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THE QUEST OF VITAMIN B_1.*

BY

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In 1929 Professor Eijkmann of Utrecht was honored with the Nobel Prize in recognition of a discovery which he made more than thirty years previously. It was he who first developed polyneuritis in fowls and recognized it as identical with human beriberi, which was then, as now, one of the great scourges of the East. To Eijkmann in Java went the honor of making the discovery. The task of convincing the practitioner of tropical medicine fell to Fraser and Stanton in the Malay States and to Chamberlain and Vedder in the Philippines some fifteen years later. Since their day we have known as a practical matter that beriberi can be prevented by leaving some of the bran on rice, which is to be used for human consumption. The immediate public health problem has long been one of popular education with respect to the need for public control, for example, by a substantial tax on polished rice so as to restrict its consumption by the masses. So slow is this process that, after twenty years of adequate knowledge, scarcely any impression has been made on the incidence of beriberi in the Orient except to a limited extent in the Dutch East Indies. The task for the publicist still remains.

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It is another phase of the matter which it is my purpose to discuss today, that of the search for the substance in rice bran which prevents beriberi, the substance which we now call vitamin B_1. After all, it seems not unlikely that the interesting and pregnant facts which have come out of that search may serve as a valuable indirect means of publicizing the Orient's need and promoting remedial action. For it has turned out that this vitamin, once associated in the popular mind with a disease seen only in remote quarters of the globe, is really one of the indispensables, not only for the life of all humankind but for all living things. It is present in nearly all our foods in amounts ranging from only 1 to 40 parts per ten million, but without it life would cease to the best of our belief. No one gets too much of it for there are no super-rich sources of supply; many both in Orient and Occident get too little, for the refining of grains and the cooking of foods reduce our intake below that which must have characterized the diet of primitive grain eating man.

All these and many more vital facts would have escaped us had we been content with the apparently practically adequate answer "Rice bran prevents beriberi." Fortunately some faint glimmering of these other, and as yet incompletely developed, possibilities entered the minds of early students of the vitamins in the Orient, in America and in Europe and embarked hundreds of men in many scores of laboratories all over the world in quest of these elusive substances. It was my good fortune to be inoculated in 1910 with a curiosity about what we then called "the beriberi preventing substance" in rice bran. The more provocative name "vitamin" was coined a year or two later. The circumstances were favorable for the idea to take root in one's mind for beriberi was very prevalent in Manila. It was the principal contributor to the enormous infant mortality of about 50 per cent which was recorded year after year, a mortality largely due to the deficiency of the prevailing diet as reflected in the mothers' milk. The human body cannot synthesize the vitamin nor can it long survive without it.

Only one of many to participate in the study, only one of many to contribute significantly to the solution of the problem, my mind nevertheless has been so largely engrossed with it

during all these intervening years that I find it difficult in retrospect to visualize how life would have seemed without this incentive.

ISOLATION OF THE VITAMIN.

The first and major task was to isolate the substance, for, unless the chemist can obtain a substance in pure condition, he has little chance to identify it. Otherwise, the properties of adventitious impurities are indistinguishable from those which characterize the essential substance just as one cannot discern the beauties of an archeological find until the accumulated encrustation of the ages is removed. This is the more so if our find is a molecule. Because of its invisible size its recognition at best depends on highly inferential evidence rather than the direct evidence of the eye.

In this case we had only one known property of the substance whereby to recognize it, namely, its ability to prevent beriberi. Chickens were first used as experimental animals, later pigeons, rice birds or rats. These were fed on beriberi producing diets, with daily additions of the substance under test. Numerous foods were tried in search of a rich source, but none better than rice polish or yeast has been found. Extracts of these foodstuffs were prepared using different solvents to determine which best separates the active substance from the bulk of the rice bran or polish. Water or dilute alcohol was found to remove it; fats solvents did not. These facts we learned by feeding the residue left after the evaporation of the solvents.

Having learned how to extract it, means were sought to remove the essential substance from the solution as selectively as possible. One of the most useful methods was to stir a certain sort of clay into the solution. When the clay settled the vitamin was no longer in the solution, but in the clay, as we found out by adding it to the diets of experimental animals during several weeks. At first these experiments were on a blind cut-and-try basis. Later we, that is the chemists in various countries, began to form the opinion from its behavior that the substance must be a nitrogen base. We could then discard many ideas as improbable because inconsistent with this opinion. Sometimes good ideas were discarded because

our opinions were only partly correct. Sometimes accidents occurred which turned out more favorably than the intended experiments would have done; much more often the accidents were unmitigated misfortunes.

As time went on we were led to believe that the growth rate of rats was a more reliable index of the presence of the vitamin than the prevention of beriberi in birds. The event proved this untrue for there were several other vitamins in our extracts which also influenced growth. We had to try to devise new diets which lacked only the beriberi vitamin so that we could use the growth rate as a true measure of the presence of our substance alone. After some years this was largely realized, though imperfectly. Others noted that the weights of birds declined as they approached the beriberic condition. This appealed to them as a more convenient index because weight loss occurs sooner than beriberi. Again another vitamin in the extracts was found which also influenced weight and confused the results. Other workers used curative tests on birds which had already been brought to a beriberic condition but birds sometimes recovered temporarily without treatment. Curative tests on polyneuritic rats were later adopted and in the opinion of many are the most reliable.

One can understand from this account how the combined efforts of scores of workers could fail for 16 years to yield even a milligram of the pure substance. The honor of first achieving this result went to Jansen and Donath, working in the same laboratory in Java where Eijkmann had discovered avian beriberi 30 years before. They made use of the expedients of many other workers and supplied many refinements of their own devising. However, the process was so long and complicated and so inefficient at certain stages that the losses were very heavy, partly from scattering in the numerous fractions and partly from destruction of the delicate substance by heat and chemical reagents. As a result they had so little vitamin that they were not able to establish the elementary composition of it. Not until 6 years later did Windaus in Germany succeed in proving that it contained sulphur in addition to carbon, hydrogen, nitrogen and

oxygen, which had previously been noted. The precise proportions of these elements was still uncertain.

More of the pure substance was needed for experiments. Ten to twenty fold better yields were obtained in 1933 by the group in New York with which I was associated. The principal improvement in the process was the use of quinine sulfate to remove the vitamin from the clay used to adsorb it. Quinine is taken up by the clay and the vitamin is displaced much more fully and with less destruction than by the alkalis previously used. This with other refinements of process resulted in yields of about 5 grams of pure vitamin per ton of rice polish. In this operation we used as vessels a 1300 gallon tank at the first stage and a 20 cc test tube in the 20th and last stage.

ITS ELEMENTARY COMPOSITION.

We were now in position to begin the study of its chemical nature. Having a pure organic substance the chemist burns a weighed specimen and weighs the carbon dioxide and water which are formed. From these figures by simple arithmetic he can calculate the carbon and hydrogen content of the specimen. By burning other specimens under suitable conditions he converts all the nitrogen to molecular nitrogen and the sulfur to sulphuric acid and calculates the quantities of these elements. Having the percentage of each of the other elements present he assumes that the rest is oxygen and proceeds to calculate the empirical formula. This is done merely by dividing the percentage of each element by the atomic weight of that element. If the quotients have a common divisor one obtains a series of integers by dividing by this divisor. These integers give the counts of the numbers of each sort of atoms present. If integers are not obtained the chemist knows his analyses are in error or his substance is impure for these are no fractions of atoms in a molecule. Vitamin B_1 was found to be $C_{12}H_{18}N_4OSCl_2$.

Had our earliest attempts to isolate the vitamin been successful we should have had to obtain a hundred fold larger quantities of the substance for study because the chemical methods then available were so inferior to those of the present day. By the older methods 100 to 200 milligrams were

required for each analysis. Now, thanks to the devices of Pregl and his successors 2 milligrams will serve the same purpose. This represents an economy of very great proportions when we are dealing with a substance which can only be obtained from nature at a cost of thousands of dollars per gram. Microchemical analysis is based upon the development of balances of extreme precision, upon a growing appreciation of the extent of adsorption of moisture films on surfaces of vessels and the development of means for their control as well as upon the invention of many clever manipulative devices for handling minute quantities. For the progress of biochemistry the development of microanalysis is probably the most significant accomplishment of this century. Without it the identification of the numerous hormones and vitamins would have been well nigh impossible.

SPLITTING A MOLECULE INTO RECOGNIZABLE FRAGMENTS.

An empirical formula is only a starting point in the chemistry of an organic substance for we must know how each atom is placed in the molecule with respect to every other. This can ordinarily be learned only by tearing the molecule into fragments which are simple enough to be recognized. Simplicity is important because all the possible compounds are known to chemists only in the case of the simpler substances. Tearing the molecule into fragments is best done, if possible, by easy stages. If in a single operation a large number of small fragments are produced one cannot guess how they were originally fitted together even if he can recognize each of the fragments. Sometimes it is necessary to chip off one small fragment at a time for identification, but this is undesirable because the remaining large fragment is still too large and complex for recognition. When possible it is best to split the molecule into two or three large fragments and subsequently to split further fragments from each of these till all the fragments are recognizable. In this way one learns a maximum about the original relationships of each fragment to the others. Suppose one were required while in a dark room to take a jig saw puzzle completely to pieces and reassemble it. He would do well first to divide it into a few sections, each containing a sufficiently small number of

individual pieces so that he could retain in his memory the relationships of each when disassembled. By so doing he could reassemble each section separately and then bring the sections together.

Of course in taking a molecule apart one cannot tell precisely where the splitting will occur. But just as cracking a nut by gentle blows will avoid crushing it into fine fragments so gentle chemical treatment is likely to split the molecule only at its weakest point. This we were able to do in the case of the vitamin by recalling to mind what seemed at that time a misfortune in trying to isolate the vitamin. We had attempted to preserve a rice polish extract against bacterial decay by the use of sulphurous acid as a preservative. The result was the complete destruction of the vitamin activity at room temperature over night.

SULFITE CLEAVAGE OF THE VITAMIN.

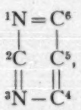
This proved to be just the sort of very gentle chemical means which served our present purpose as very few chemical bonds can be split by such a mild treatment. In this way we obtained from the pure vitamin two fragments. These on analysis in the manner described above had the compositions shown in the following equation:

$$\underset{\text{Vitamin}}{C_{12}H_{18}N_4SOCl_2} + H_2SO_3 \rightarrow \underset{\text{I}}{C_6H_9N_3SO_3} + \underset{\text{II}}{C_6H_9NSO} + 2HCl$$

In this splitting every atom was accounted for and the sum of the weights of the products isolated equalled the weight of the starting substances. We knew we had split the molecule neatly into two pieces without any chips. This was a piece of rare good fortune.

Of these products, I has very unusual stability as it does not melt or decompose on heating up to 400° C. On heating with water it yields sulfuric acid; with alkali sulphur dioxide. These properties characterize sulfonic acids, i.e., acids containing the group $-SO_3H$. But in these further splittings we had broken the rest of the molecule into such small fragments that we could learn nothing more from them. However, the ultra violet absorption of the substance, I, gave us a clue for its ultra visible color resembles strongly that of

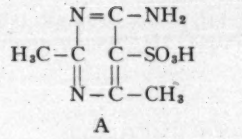
certain pyrimidine compounds. Pyrimidine compounds contain the ring,



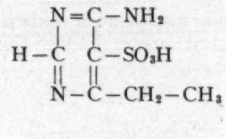
the atoms of which are conventionally numbered as shown. Our compound I on heating with strong acid yielded ammonia, from which we inferred that there must be an amino group, $-NH_2$, secured to the ring. The difficulty with which it split out was more consistent with the idea that the amino group had been on No. 6 carbon atom than elsewhere. Accordingly we began to speak of the sulphite cleavage product, I, as a 6-amino sulfonic acid. What was left after splitting out the ammonia had the composition, $C_6H_8N_2SO_4$. We called it a 6-oxysulfonic acid because it still retained the sulfonic group and an oxy group, $-OH$, in place of the original amino group.

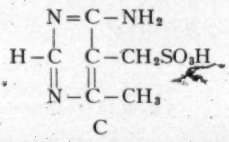
IDENTIFICATION OF PYRIMIDINE PORTION.

Assuming the amino sulfonic acid, $C_6H_9N_3SO_3$, really contained the pyrimidine ring, C_4N_2, the amino group, $-NH_2$, and the sulfonic group $-SO_3H$, we could by subtraction conclude that 2 carbon atoms and 6 hydrogen atoms must still be accounted for. How could these extra atoms be disposed about the pyrimidine ring? Since no carbon containing groups could be detached from the ring by heating with hydriodic acid to form methyl iodide or its homologs it was unlikely that either of these extra carbon atoms was attached to the nitrogens of the ring. This follows from the general experience of chemists that carbon is more firmly attached to carbon than to nitrogen. We also had reason to believe that some group was attached to the No. 5 carbon of the ring, since if there were only a hydrogen on this carbon it would be readily replaced by bromine, which was not the case. According to such reasoning the following seemed to be among the more probable structures for the amino sulfonic acid:

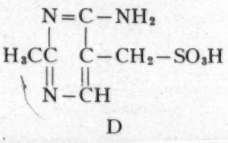


A





C



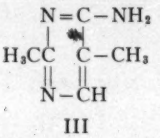
D

Each one of these represents an entirely distinct compound although they contain the same number and kind of atoms and although there is a strong similarity among them as to the major part of the structure. The four so-called position isomers represented above are only illustrative examples. Many other permutations and combinations can be written which are not in conflict with the information which we then possessed.

By treating the amino sulfonic acid with metallic sodium in liquid ammonia we obtained a pure substance which was analyzed and found to have the composition $C_6H_9N_3$. We had evidently removed the sulfonic group and replaced it by hydrogen. The resulting product melted at 201–202° C. and formed a beautifully crystalline picrate melting at 222°, having the composition $-C_{12}H_{12}N_6O_7$. The entire experiment including all of the analyses of the resulting base and its picrate was performed with 27 milligrams of the amino sulfonic acid.

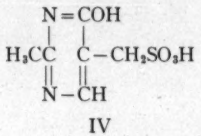
In the meantime we had prepared synthetically all of the possible isomers of this compound containing a pyrimidine ring with an amino group on No. 6 carbon atom. Some of them were not previously known but we could prepare them by analogous methods, varying the positions of the substituent groups by choosing starting materials with appropriate groups in appropriate positions. Only one of these isomers melted at 201°–202° C. and formed a picrate melting at 222° C. When we mixed the picrate of the synthetic substance with the picrate obtained from the vitamin the melting

point was unchanged. Their identity was thus established. The sacred isomer had the structure, III: By an analogous synthesis



III

2,5 dimethyl-6-amino-pyrimidine



IV

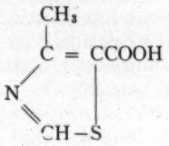
2 methyl-6-oxypyrimidine 5 methyl sulfonic acid

compound IV was prepared and found identical with the oxysulfonic acid from the vitamin. One of the major sections of our jig saw puzzle was fitted together at last.

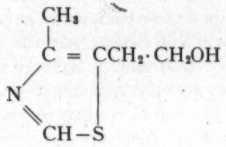
THE THIAZOLE FRAGMENT.

The other section or fragment had been assembled much more easily for reasons which will presently be clear. Product II of the sulfurous acid cleavage on oxidation with nitric acid yielded forthwith a compound $C_5H_5NSO_2$, which was already known to science. It had been prepared synthetically in 1890 by a man named Wöhmann, who had no specific idea at the time that the substance or the information would ever be useful to us or to anyone. But for generations it has been the practice of organic chemists to store away facts of this kind in convenient form for future reference. Richter's lexicon of the compounds of carbon and its successors provide us with a catalog of all the hundreds of thousands of organic compounds which have been previously described. They are arranged in this catalog not alphabetically by their names, but serially according to the numbers of carbon atoms and other atoms which they contain. There, listed among the compounds of 5 carbon atoms, we found one which tallied in composition, melting point and other known properties with the substance obtained from the vitamin. Should the barbarians of the future ravage our civilization and destroy our libraries let us hope that a copy of this catalog will survive. Chemists could reproduce the methods of chemistry from memory but these details are so voluminous that they are preserved only on paper.

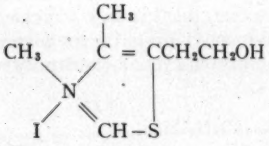
The compound in question is known as 4-methyl-thiazole-5-carboxy acid, V.



V.



II.



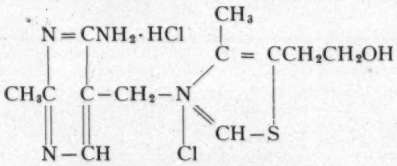
VI.

Since the nitric acid oxidation of the split product of the vitamin had removed but one carbon atom in transforming C_6H_9NSO into $C_5H_5NSO_2$ and since the group COOH is the usual result of the oxidation of a carbon atom side chain it was a relatively simple matter to reconstruct the split product as shown in formula II. If the hydroxyl in the side chain had been on the first carbon atom instead of the second our split product would rotate the plane of polarized light which was not the case. To clinch the matter, product II, called 4-methyl, 5 (β hydroxy) ethyl thiazole was presently synthesized by condensing thioformamide with bromaceto-propyl alcohol.

UNION OF THE PRIMARY FRAGMENTS.

The two fragments having been reconstructed we must find how to fit them together. From its method of formation we could be sure that the sulfonic group marked the place of attachment on the pyrimidine portion. The place of attachment on the thiazole portion was at first not so clear. But by adding methyl iodide to the nitrogen of II we obtained a substance, VI, which behaved like the vitamin itself in certain peculiar ways. On adding alkali drop by drop to a solution

of the salt of either substance, one can observe that the alkalinity does not remain constant after each drop. If one uses an indicator one sees that the alkalinity established immediately after each addition declines in a few moments to nearly its initial value and the amount of alkali required to establish a permanent level of alkalinity represents 2 more molecular equivalents than would normally be expected. This phenomenon is due to intramolecular rearrangements which we need not describe. Suffice it to say that the fact that the peculiarity was common to both the vitamin and the methiodide of the split product satisfied us that in the vitamin the pyrimidine portion was attached to the thiazole in the place of the methyl group on the nitrogen of the methiodide. The vitamin could then be mentally reconstructed as:



Vitamin B_1 chloride hydrochloride.

SYNTHESIS OF VITAMIN.

Now for the actual verification by synthesis. We could not remake the vitamin from its split products because the amino sulfonic is so stable that it will not react with the thiazole portion. But by analogous means it was possible to synthesize the corresponding pyrimidine in which a bromine replaces the sulfonic group. When this is gently heated with the thiazole the desired combination occurs. When 6 to 10 micrograms of the resulting product was injected into paralyzed beriberic rats they recovered the use of their limbs over night. The twenty-six year goal was achieved.

The synthesis has since been put into commercial operation and the pure synthetic material is finding an increasing use in medicine, particularly for the treatment of neuritis and arthritis as well as beriberi. A marked increase has already been noted in the volume of experiments having to do with

its function. The thiazole nucleus which it contains had never before been found in nature but it seems to play a fundamental rôle in living things. The pyrimidine nucleus has long been known and is of very widespread occurrence in tissues. It has already been shown that in combined form the vitamin functions as an enzyme in animal tissues to dispose of the otherwise half burned products which are formed from the metabolism of sugars and starches. In plants it stimulates root growth which explains why it is so much concentrated in seeds. The fuller significance of the vitamin will doubtless continue to develop for several years to come. Will the facts evinced be dramatic enough to teach man at large no longer to disdain to fill his belly with the husks which the swine do eat?

Potential Uses of Indium.—(*Compressed Air Magazine*, Vol. 42, No. 8.) From a laboratory curiosity a decade or so ago, indium, one of the rare metals, is gradually becoming a commercial product, and, together with its related elements gallium and thallium, is attracting attention because of its possible practical applications. Indium is a soft white metal of low melting point—310° F.—and is present in very small quantities in many ores, especially in zinc-blendes. It is now being recovered as a by-product in the making of zinc in Arizona. Present indications are that jewelers and silver-smiths will be the largest potential users. Investigation has revealed that unusual color effects in jewelry can be obtained by means of indium. When gold and indium are plated alternately on silver, the article becomes sky-blue when exposed to heat, while interdiffusion of layers of silver, indium, and palladium at 1500 deg. F. yields a fine rose pink alloy. There is a possibility that indium, in combination with Lipowitz's alloy—bismuth, lead, tin, and cadmium—may find application in the making of casts and impressions. The latter has the lowest melting point of the fusible alloys generally available, and with indium the metallurgists have succeeded in reducing it to a point where it is slightly above the normal temperature of the human body. This means that the metal consisting of 18 per cent. indium and 82 per cent. Lipowitz's alloy, can in the fluid state be brought in contact with the body without causing it discomfort. Possibly the day may come when it will be used instead of plaster of Paris in making casts.

R. H. O.

CLOUD CHAMBER INVESTIGATIONS OF SOME COSMIC-RAY INTERACTIONS WITH MATTER.*

BY

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I. INTRODUCTION.

BARTOL RESEARCH FOUNDATION
Communication No. 95.

Some cosmic-ray interactions with matter unquestionably involve nuclear disintegrations. It may reasonably be hoped that the complex phenomena involved in these disintegrations will ultimately be resolved and linked with nuclear interactions produced by emissions from high-voltage machines. So we may regard cosmic rays as a valuable means of studying nuclear reactions and energy transformations involving energies that transcend those obtainable by any other means. Yet, it becomes increasingly clear that cosmic-ray interactions with matter are very complex, not only as a class, but often individually, as well. Cosmic rays are conglomerate, both in nature and energy, at the surface of the earth, and even at high elevations in the atmosphere. Some of their energies have been shown to exceed 5×10^9 volts. Energy transformations produced by particles of extremely high energies are not yet well understood, and may closely resemble those produced by quanta; so investigations of cosmic-ray interactions are usually complicated by uncertainty as to the nature of the rays producing them.[1]

Another complication in the analysis of cosmic-ray effects is the production of chain reactions, wherein a single primary ray ejects high-energy secondaries whose absorption causes secondary points of emission to appear in surrounding matter,

* Presented, in part, at American Physical Society meetings: *Phys. Rev.*, **45**, 296A (1934); *Phys. Rev.*, **50**, 394A (1936); *Phys. Rev.*, **51**, 386A (1937).

[1] We shall use the unmodified term "cosmic ray" to designate any individual quantum or particle of cosmic-ray origin, whether primary or secondary, without designation of its energy, charge, mass, or of any other characteristic.

thereby increasing the total number of rays observed, by multiplicative processes. Most of the large sprays observed in cloud chambers diverge from more than one point; sometimes the secondary centers of emission are so numerous that it is impossible to count them; sometimes they are so close together that they resemble a single point. If these "showers" are initiated in the atmosphere, or in other overlying material at considerable distance from the point of observation, their component rays pass through the apparatus in nearly parallel directions. The observer has no way of knowing whether a cosmic-ray disintegration or other interaction which he observes with his apparatus represents the whole or only a small fraction of the energy of the primary cosmic ray that produced it, because of the finite dimensions of the apparatus.

In spite of these and other complications, very valuable information has been derived from cloud photographs of cosmic-ray interactions, made by Anderson and Neddermeyer,[2] Blackett,[3] Street and Stevenson,[4] Brode, MacPherson and Starr,[5] and their collaborators, and by many others. The use of cloud chambers whose expansions are controlled by Geiger-Müller counters (introduced by Blackett and Occhialini)[6] facilitates the collection of pictures of large numbers of cosmic-ray interactions, and makes possible a partial selection of particular cosmic-ray phenomena, by the use of suitable configurations of the controlling counters. A cloud chamber operated in a strong magnetic field presents a particularly effective means of investigating the details of cosmic-ray interactions, since it shows the kinds of charge and the $H\rho$ values of most of the charged particles passing through it. The only disadvantage of a large magnet, for some work, is its contribution of secondary centers of emission.

[2] C. D. Anderson, R. A. Millikan, S. Neddermeyer, and W. Pickering, *Phys. Rev.*, **45**, 352 (1934); C. D. Anderson and S. Neddermeyer, *Phys. Rev.*, **50**, 263 (1936); C. D. Anderson and S. H. Neddermeyer, *Phys. Rev.*, **49**, 415A (1936).

[3] P. M. S. Blackett and R. B. Brode, *Proc. Roy. Soc.*, **A154**, 573 (1936); P. M. S. Blackett, *Proc. Roy. Soc.*, **A159**, 1 (1937), and *ibid.*, p. 19.

[4] J. C. Street, E. G. Schneider and E. C. Stevenson, *Phys. Rev.*, **48**, 463 (1935); E. C. Stevenson and J. C. Street, *Phys. Rev.*, **48**, 464 (1935); E. C. Stevenson and J. C. Street, *Phys. Rev.*, **49**, 425 (1936).

[5] R. B. Brode, H. G. MacPherson, and M. A. Starr, *Phys. Rev.*, **50**, 383 and 581 (1936); R. B. Brode and M. A. Starr, *Phys. Rev.*, **51**, 1006A (1937).

[6] P. M. S. Blackett and G. P. S. Occhialini, *Proc. Roy. Soc.*, **A139**, 699 (1934).

It is difficult to think of any counter configuration that does not make some sort of selection of the type of phenomenon photographed. Thus, control by collinear coincidence counters above and below the chamber requires that an ionizing ray shall pass through the chamber, or that two or more ionizing rays shall be emitted in appropriate directions by a burst or shower in the vicinity. Selection of interactions caused by non-ionizing rays is equally possible, if one covers the apparatus with a layer of "shielding counters," connected to the coincidence circuit by a reversing stage of amplification. The writer's previous experiments with counter-controlled cloud-photography were made with counters that were out of line.

In the present experiments, groups of two or of three coincidence counters are arranged side by side in a *horizontal* line, in several configurations above and below the cloud chamber. Slabs of various materials are placed in different geometrical arrangements with respect to the counters and chamber, in the several series of observations. The horizontal counter arrangements mainly select pluralities of rays traveling in the downward direction, and were chosen as among the least restrictive ones that require more than one ionizing ray in the vicinity of the chamber, without requiring that an ionizing "primary" ray shall be incident on the apparatus. The arrangements are, of course, susceptible to sidewise-directed rays of primary or secondary origin. However, at sea-level, the number of primaries incident from the side is almost negligible within the small solid angle subtended by the counters. Sidewise-directed secondaries, distinguishable by the fact that they are accompanied by one or more other rays through the chamber, are frequently seen in pictures taken with the present arrangements.

II. EXPERIMENTAL ARRANGEMENTS.

The cloud machine has already been described.[7] The rectangular cloud chamber, 15.5 cm. by 12.0 cm. by 5.0 cm., has an atmosphere of argon gas (96 per cent. A + 4 per cent. N_2), saturated with *n*-propyl alcohol. The pressure of the cloud atmosphere is 68 cm. of mercury, when expanded; the

[7] G. L. Locher, *R. S. I.*, 7, 471 (1936).

isothermal expansion ratio of the gas is 1.118; and the time of the expansion is 0.013 sec. The direction of expansion is horizontal.

No magnetic field is applied to the chamber. The apparatus is constructed mainly of Dowmetal, and is operated near the center of a large room in a building whose water-equivalent is approximately two meters, distributed in three overlying layers. The building is near sea-level.

Photographs are taken with Leica cameras equipped with Elmar lenses (5 cm. focal length), arranged with their optic axes intersecting at 30° in the center of the chamber, at apertures of F/7 to F/9. The entire chamber is adequately well in focus, since the apertures are small. Eastman sound-recording positive film is used, because of its high contrast and fineness of grain. The film is post-fogged with diffuse white light (roughly 4×10^{-7} candles per cm.^{2}; 5 seconds), and developed in Eastman D-72 developer for 20 minutes at 17° to 18° C. The fogging increases the sensitivity of the film by a factor of about two, without appreciably blackening it.

Two hundred controlled pictures were taken with the light from No. 10 Photoflash lamps, whose time of useful illumination is estimated to be, roughly, 0.01 sec. For subsequent pictures, and at the present time, a spark illuminator is used. The light is produced by the discharge (in air) of an 8-m.f.d. condenser, charged to 3000 volts, between electrodes of calcium and magnesium; the time of useful illumination is estimated to be 10^{-4} sec. The use of very short intervals of illumination provided by these sources makes it easy to count the drops in pre-expansion tracks along which the specific ionization is sufficiently low, and it eliminates turbulence in the gas arising from thermal irregularities in the chamber, caused by heat from the light source.

An interval of approximately 0.05 sec. is allowed to elapse between the end of the expansion and the instant of photography, to provide for the growth of drops to a size large enough to photograph. The diameters of the drop images on the film depend on this time and on the amount of spreading of the photographic image, during development. The *mean apparent diameter* of the drops, computed from their mean photographic diameter (0.03 to 0.04 mm.) and the magnifica-

tion of the cameras (0.20), is approximately 0.15 to 0.20 mm.; this is certainly larger than their actual size in the chamber.

Great care was used in assembling the cloud chamber to avoid contamination with radioactive material. Once assembled, the apparatus was used for a year, without any alteration or adjustment. In late pictures of this sequence, dirt, resulting from the action of the alcohol on the rubber compound used for sealing on the windows, crept over the circumference of the windows, and shows in the photographs. This was removed when the chamber was dismantled for the insertion of the lead and aluminum plates used in the second set of exposures.

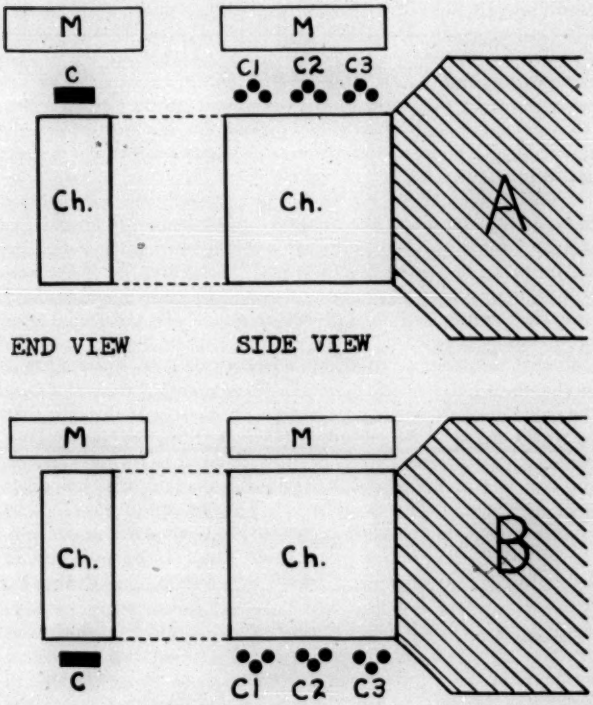
The electric field for sweeping out old ions was applied between the case of the chamber and a pair of cross-wires intersecting in the center of the chamber, during the collection of the first 660 controlled pictures. For potential differences of 23 and 46 volts, the character of the pictures seems to have been the same; a potential difference of 180 volts distorted pre-expansion tracks. In the second series of exposures, the field (7.5 volts $cm.^{-1}$, minimum) was applied between the case of the chamber and the central slab of metal. In both cases, the arrangement was such that no charge could leak directly on to the glass of the chamber, because it has previously been observed that a charge may become isolated on a glass window, and produce distortion of the tracks by its field, which persists after the electrode is earthed.[8] The sweeping electrode is earthed when the expanding system has moved about 0.2 mm.

In the earlier series of pictures, there is no evidence of distortion of pre-expansion tracks other than: broadening by diffusion during the interval between the passage of rays through the chamber and the time at which diffusion is stopped by the growth of drops; broadening due to the 12 per cent. expansion of the atmosphere; slight distortion due to the fall of drops. In the later series, the lead and aluminum plates caused distortion of tracks in their vicinity, as the result of interruption of the flow-stream of the expanding gas

[8] No evidence of "electric wind," as observed by Blackett (reference 9) was found in this chamber. But the writer confirms Blackett's observation of this troublesome phenomenon, in other chambers of the circular glass type, when the sweeping electrode is in contact with the glass.

by the riveted joint between the metals. The photographic diameter of electron tracks formed just before expansion is

FIG. 1.



Configurations of cloud chamber (*Ch.*), counters (C_1, C_2, C_3), and the overlying material (*M*).

0.5 mm., approximately, which is in adequately good agreement with the value computed from Blackett's formula.[9]

The configurations of the coincidence counters used for controlling the expansions are shown in Fig. 1. The number

[9] P. M. S. Blackett, *Proc. Roy. Soc.*, **A146**, 281 (1934).

of controlled photographs taken with each configuration is listed in Table I, column 4; the average interval between expansions is given in column 5. Each counter unit consists of three argon-filled counters whose sensitive areas are 3 cm. by 1 cm., connected in parallel to a single stage of the coinci-

TABLE I.

Data on Controlled Pictures Made with Arrangements Shown in Fig. 1.

Series Number.	Material over Chamber (Fig. 1-*A*).	No. of Controlling Counters.	No. Pictures.	Ave. Time between Expansions (minutes).
I to IV	Paraffin 5 Kg; 10 g/cm²	2	100	12
VI	Lead 18 Kg; 55 g/cm²	2	50	13
VII	Aluminum 10 Kg; 19 g/cm²	2	70	14
IX	Lead 27 Kg; 70 g/cm²	2	55	21
X	Lead 6 Kg; 19 g/cm²	3	25	174
	(Fig. 1-*B*)			
XI	Lead 6 Kg; 19 g/cm²	3	19	180
XII	Paraffin 6 Kg; 19 g/cm²	3	29	112
XIII	Paraffin 6 Kg; 19 g/cm²	2	50	50
XIV	Nothing	3	23	107
XV	Aluminum 2.3 Kg; 18 g/cm²	3	15	186
XVI	Aluminum 2.3 Kg; 18 g/cm²	2	57	39
XVII, XVIII	Nothing	2	117	43
XIX	Lead 6 Kg; 19 g/cm²	2	200	15
XX	Lead 6 Kg; 19 g/cm²	3	100	138

dence circuit. Each unit thus presents a sensitive area of 9 cm.². The resolving time of the individual tubes is approximately 0.002 sec.; the counting rates of individual tubes is 8 per min., and of each unit, 20 per min. The resolving time of the amplifier, for coincidence counting is approximately 10^{-5} sec. From these data, the efficiencies of one, two, and three units are computed to be: 99.9 per cent., 99.85

per cent., and 99.8 per cent., respectively, for counting true coincidences; the spurious coincidence rates due to random rays are: 8×10^{-3} per hr., for double coincidences, and 7×10^{-8} per hr., for triple coincidences. So the loss of true coincidences and the introduction of spurious ones may be neglected.

In view of the possible bearing of seemingly trivial information about experimental arrangements on the interpretation of photographs in the light of later information, the writer records as many as possible of the conditions attending the photography of the tracks, for later reference.

In the course of these experiments, all radioactive sources were kept as far from the room containing the apparatus as possible; no neutron sources were in the vicinity, at all; and there was no high-voltage apparatus in operation. So the effects dealt with should have been confined to cosmic rays and natural radioactivity.[10]

III. RESULTS AND DISCUSSION.

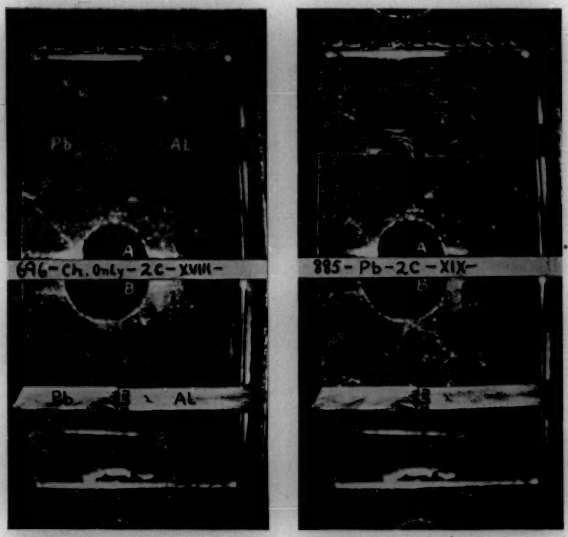
Figures 2 to 12 show stereoscopic pairs of photographs obtained during the several series of observations. Each pair is labeled, successively, with: the number of the exposure, the kind of material put over the chamber, the number of controlling coincidence counters, and the series (Fig. 1 and Table I). The pictures may be viewed with an ordinary stereoscope. The magnification of the photographs is $\times 0.4$. The top of the chamber is shown at the top of each member of the pair (A and B), and the direction of expansion is sidewise, from right to left. Dirt on the windows of the chamber can be recognized by its appearance on successive photographs, and by the fact that it falls in the foreground or background, upon stereoscopic examination. For convenience of reference in the legends of the photographs, the center of the chamber is taken as the origin of rectangular coördinates, and the quadrants are numbered I, II, III, and IV, anti-clockwise.

An effort has been made to collect a sufficiently large number of pictures, with each configuration, to get an idea of the "representative" phenomenon selected. Only a rough

[10] All measurements are, of course, made from the original negatives, since cloud photographs almost invariably suffer in photographic reproduction.

idea can be thus obtained, because of the dependence of the nature of the phenomenon selected on the amount, distribution, and kind of material in the vicinity, and because of the inability of any arrangement of controlling counters to sharply

FIG. 2.



Typical small showers of high-energy rays and low-energy rays, respectively, photographed with 2-counter control. In 696, the specific ionization of one of the rays passing through the aluminum plate (arrow) is 72 pairs per cm. One oblique ray (two arrows) has a specific ionization of 30.3 per cm. The low-energy electrons, in 885, are probably mostly recoil electrons from γ-rays emitted by shower electrons and positrons, and/or recoil electrons from recombination radiation of positrons from a large shower in overlying material.

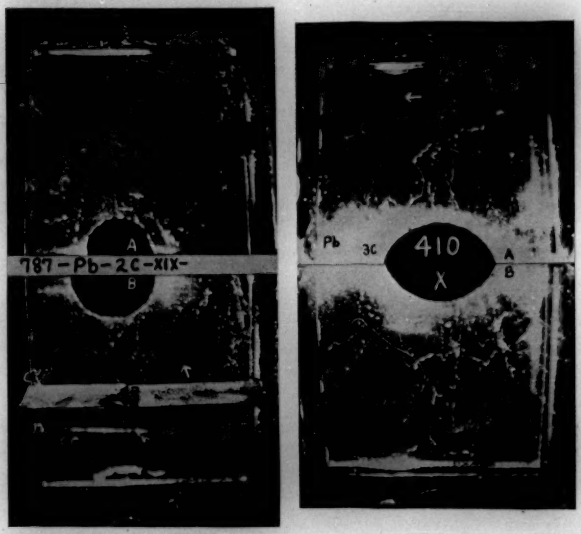
select particular types of phenomena from the widely varied forms of large cosmic-ray interactions.

Number of Pictures with Tracks.

About half of the pictures show no tracks attributable to cosmic rays. These doubtless result from coincidences due to sidewise-directed rays that do not pass through the chamber,

and from groups of simultaneous rays that pass through the counters but not through the chamber. One may determine the approximate fraction of the expansions that lead to cosmic-ray track photographs, although individual cosmic-ray tracks are not always distinguishable from those due to

FIG. 3.

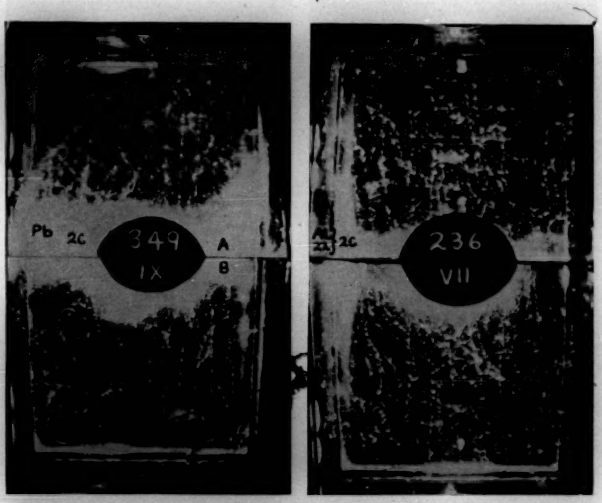


Typical larger showers, predominantly of high-energy and of low-energy rays, respectively. Many of the rays in 787 pass through the aluminum plate; one oblique ray (arrow) has a specific ionization of 51.8 per cm. In 410, a post-expansion electron (arrow) emerges from the top of the chamber.

radioactivity. Criteria applied to this distinction include: (*a*) the state of diffuseness of the tracks; (*b*) alignment of the tracks with the controlling counters; (*c*) the plurality, or singularity, of the rays; (*d*) ability of the rays to penetrate sheets of matter in the chamber; and (*e*) relative frequencies of occurrence of pictures with and without tracks, on counter-

controlled and on random photographs. These criteria may be applied both to electrons and to nuclear tracks, although some are mostly applicable to electrons only. The energies of the rays are poor criteria for this purpose, since, for example, showers containing very numerous electrons, nearly all of which are of low energy, are frequently photographed.

FIG. 4.



Showers of 50 or more rays, mainly of high energy, emerging from widely separated points. The numerous small branches, due to collisions and to Auger effect, give the tracks a beaded appearance.

Figure 13 shows the distribution of sizes of groups of pre-expansion electron tracks whose photographic breadths indicate that they were formed simultaneously, just before expansion. The selection of larger sizes by three counters than by two is shown by comparing the two series: XIX (lead; 2 counters; 200 exposures collected in 50 hours of operation), and XX (lead; 3 counters; 100 exposures collected in 230 hours of operation).

Pre-expansion and Post-expansion Tracks.

The short time of illumination of the chamber makes it very easy to distinguish between pre-expansion and post-expansion electron tracks, and to tell, within fairly good limits, about the simultaneity of tracks of similar specific ionizations.[11]

FIG. 5.

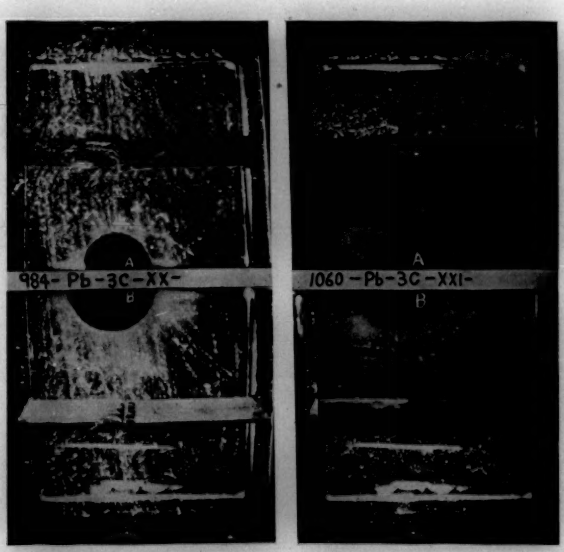
430: shower of about 80 rays, mostly of high energy, converging to a point, or to several close points, near the top of the chamber. 415: shower containing very numerous low-energy electron tracks and one track (arrow) that is probably caused by a nucleus; the specific ionization along the latter is > 300 pairs per cm., and its visible length is 7 cm.

The presence of numerous post-expansion electron tracks on controlled photographs lead to the examination of the relative numbers of photographs showing post-expansion tracks, on controlled and on random exposures. (As many as 5 post-expansion electrons were observed on a single picture.) Of

[11] Unless otherwise specified, the term "pre-expansion track" refers to a track made by a particle that passes through the chamber immediately before the expansion, and is not perceptibly diffused by the sweeping field or thermal agitation.

931 controlled photographs, taken from most of the series, 46 pictures, of 5.0 per cent. showed one or more post-expansion track. Of 200 random pictures, 11, or 5.5 per cent. showed post-expansion tracks. So the present observations show no evidence of β- or γ-radioactivity induced in the chamber by

FIG. 6.



Two large showers of rays, from above, and from the side, respectively. In 984, the very numerous rays pass through the chamber in nearly parallel directions, so they must have originated at a considerable distance above the chamber. Many of them pass through the lead and aluminum plates across the chamber. This is the largest shower yet photographed with this apparatus. The shower shown in 1061 is unusual because of its large size. Sidewise showers are frequently photographed, but they rarely contain more than 20 rays.

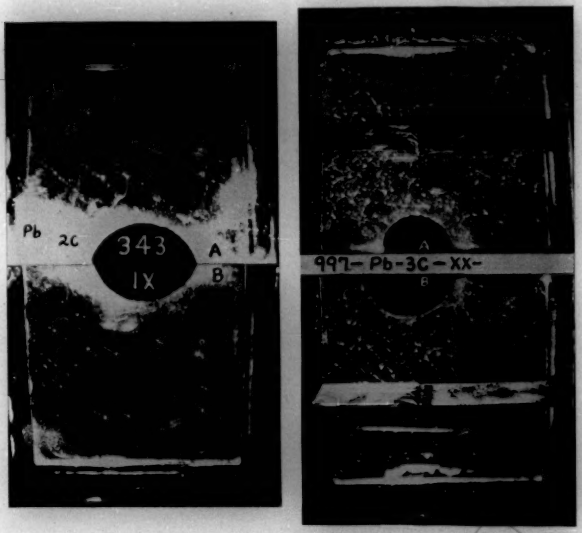
cosmic-ray interactions, although the method is considered to be very sensitive to the detection of such radioactivity.

Specific Ionization of Electrons.

Ion counts were made on nine excellent shower-electrons (46 cm.). Their average specific ionization in argon at 68 cm.

is 76.8 pairs per cm.; individual tracks ranged from 30.3 to 79.0 pairs per cm. The high specific ionization observed is interpreted to mean that particles of energy $< 10^6$ volts are included in the counts. Allowing a pressure factor of 68/76, or 0.895, and an electron-density factor of 18.0/14.4, or 1.12, the mean specific ionization along these tracks, in air at the

FIG. 7.

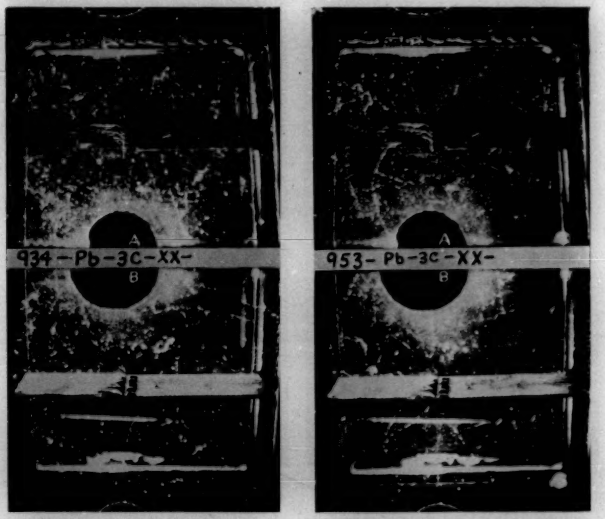


343: typical sidewise shower, containing 7 tracks that do not converge to any point nearer than 25 cm. from the center of the chamber. 997: shower of about 50 rays, obtained with 3-counter control. All of these rays are of low energy, as indicated by their curving paths; they evidently originate from abundant γ-radiation ($< 10^8$ volts) emitted by a large shower elsewhere in the building.

same temperature, would be 68.7 pairs per cm. Ion counts of this type can only be made along tracks such as those shown in Fig. 14, *a* and *b*, in which the clusters are sufficiently well resolved to allow all the drops to be counted, and in which the background due to fog and to old tracks is low. In any case, clusters introduce the most serious difficulty in ion counting.

The writer believes that cloud chamber determinations of specific ionization of electronic tracks are better than those to be made by any ionization chamber method, because there is little uncertainty as to the *singularity* of tracks along which the ionization is being measured, in a cloud chamber, whereas ionization chambers contribute simultaneous and indis-

FIG. 8.



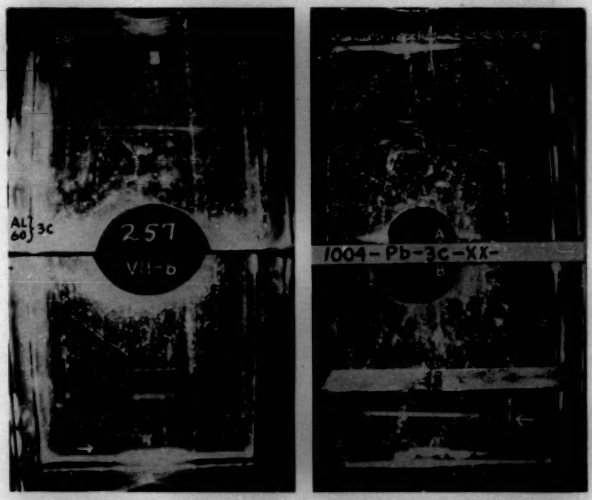
Typical large showers, selected with 3-counter control. These usually contain rays of varied energies, arising from numerous points. In 953, the tip of an old nuclear track appears at the lower corner of quadrant IV.

tinguishable secondaries by radiative processes and pair-formation.

The observation of rather numerous sidewise-directed small showers, and, more particularly, the frequent occurrence of pictures with several simultaneous low-energy electron tracks, leads the writer to the opinion that a considerable fraction of the (low-energy) γ-radiation observed in the building (or any

building) may be from cosmic rays—specifically, from radiation along the paths of high-speed electrons and positrons, from positron annihilation radiation, and from showers and bursts. Unfortunately, it seems difficult to devise an experiment by which one could unambiguously determine the frac-

FIG. 9.



Examples of close groups of rays that resemble single straight tracks of high specific ionization, along parts of their paths through the chamber. 257 shows 9 pre-expansion tracks and one post-expansion one (arrow). Three of the pre-expansion rays pass vertically through quadrants I and IV, splitting up in the lower part of the chamber. In 1004, the close group (arrow) is part of a shower of about 40 rays, and comes from the aluminum plate in the chamber.

tions of the γ-radiation due to cosmic rays and to natural radioactivity, in a given location.

Close Groups of Electrons.

Without the use of a magnetic field, it is difficult to exclude the possibility that a single straight track segment of high specific ionization may be due to a close group of electron rays, individually of low specific ionization. Several groups were

photographed along portions of which the tracks were indistinguishable from a single dense track. Fig. 9 shows two such cases; the fact that both occur under aluminum is interesting, but probably fortuitous. Any close group should, of course, become separated by scattering and straggling, after a sufficient length of path.

Nuclear Tracks.

Figures 10, 11, and 12, show a selection of nuclear tracks photographed under various materials. The fractions of the pictures on which nuclear tracks appear are given in Table II.

TABLE II.

Fractions of Pictures Showing Nuclear Tracks.

Material over Chamber.	Series.	Number of Pictures.	Pictures with Nuclear Tracks.	Fraction with Nuclear Tracks.
A. Lead	VI, IX, X, XI, XIX, XX	452	25	0.055
B. Aluminum	VII, XV, XVI	142	15	0.106
C. Paraffin	I–IV, XII, XIII	179	20	0.112
D. Nothing	XIV, XVII, XVIII	140	2	0.014
E. Random Exposures		285	6	0.021

Collected fractions with nuclear tracks:

Series *A*, *B*, *C*, and *D*: 62/913 = 0.068

Series *A*, *B*, and *C*: 60/773 = 0.078

Ratios to Series *E*:

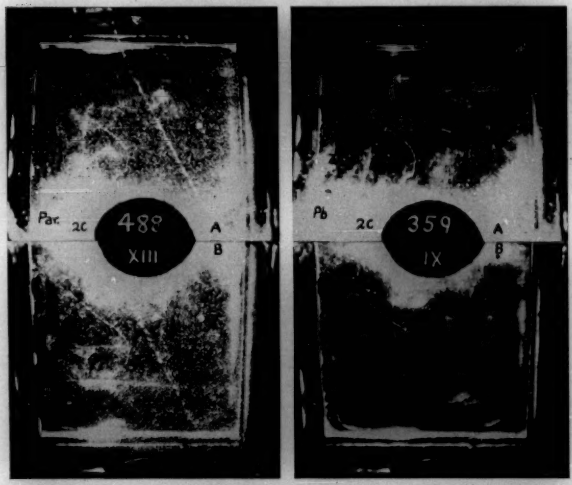
(Series *A*, *B*, *C*, and *D*)/(Series *E*): 0.068/0.021 = 3.24

(Series *A*, *B*, and *C*)/(Series *E*): 0.078/0.021 = 3.70

The data in this table, collected from the series of observations given in Table I, definitely indicate that part of the nuclear tracks photographed in these series must have originated in cosmic-ray interactions, since about three and one-half times as many of the controlled photographs show nuclear tracks as do the random ones. The long average intervals between successive expansions of a chamber arranged to select pluralities of rays passing through very restricted areas have made it impossible, as yet, to base these observations on large numbers of photographs. But the magnitudes of the ratios, and the consistency with which more nuclei appear under some materials than under others, lends strong support to the belief

that the phenomenon is real. The writer first observed nuclear particles with another cloud machine, controlled by non-coplanar counters.[12] The areas of these counters were large, and they were placed at greater distances from the chamber than in the present case. Large amounts of lead,

FIG. 10.



488: straight track of high specific ionization. Microscopic examination of the negatives indicates that the track is due to a single particle, not to a close group of electrons. Its appearance under paraffin suggests that it may be a recoil proton of very high energy. 350: post-expansion track from top of chamber (arrow) ending in the gas. The specific ionization at the top of the track is sufficiently low that some individual drops can be seen, but it increases rapidly along the path, as shown in Fig. 14-*d*. An electron of similar range would be more bent by collisions, and a proton near the end of its path would have higher specific ionization along the length of path shown. It is accordingly thought that this may be a "heavy electron" track. For comparison, 885, 787, and 696 show pre-expansion electrons at the ends of their ranges, and 410 shows a post-expansion track at the end of its range.

aluminum, and paraffin were successively stacked about the apparatus. This machine (horizontal cloud chamber) was discarded because of its form and its relative slowness of expansion, also because the question of radioactive contamination of the cloud chamber had been raised. Particular care

[12] G. L. Locher, *Phys. Rev.*, **45**, 269A (1934).

has been taken with the new apparatus to avoid, as far as possible, any radioactive contamination; the small number of nucleus-bearing photographs, on random exposures, indicates that the α-emission is low.

Blackett has pointed out that asymmetry of the sweeping

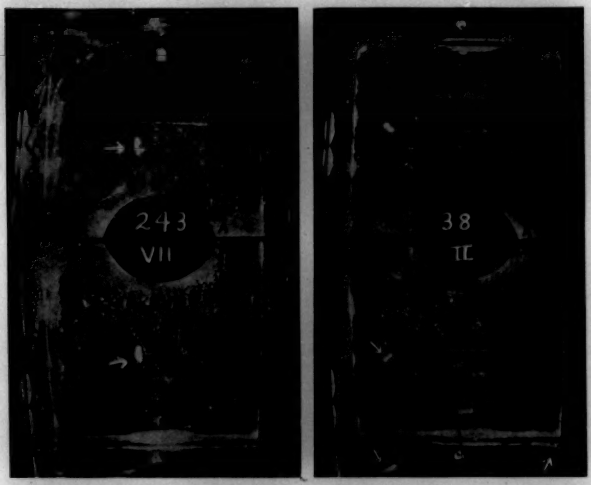
FIG. 11.

999: large shower of rays of various energies, and one or two nuclear tracks (arrow). The heavy track may be a single track, separated by the field, although the difference in origin indicates that two tracks exist. 247: pair of small globular clusters (arrows), completely in the gas, and definitely not attached to any other track. Their state of diffusion indicates that they are probably separated ions from a single cluster like that shown in 243. Clusters of this type have been seen on counter-controlled pictures, but not on random ones, so they are attributed to some cosmic-ray interaction.

field in the chamber must be considered, because of the possibility that, in regions of low field intensity, there may be agglomerations of ions that persist for long times.[9] In the first 660 pictures taken with the present apparatus, the sweeping electrode consisted of a pair of cross-wires; the sweeping field had a minimum of 3 volts cm.$^{-1}$, with 23 volts

(minimum ever used) on the sweeping electrode. The distribution of nuclear tracks and old ionic clusters about the chamber showed no evidence of asymmetry: the tracks originated from random points about the circumference of the chamber—chiefly from the top and bottom plates. In the later series of exposures, the field was applied between the

FIG. 12.



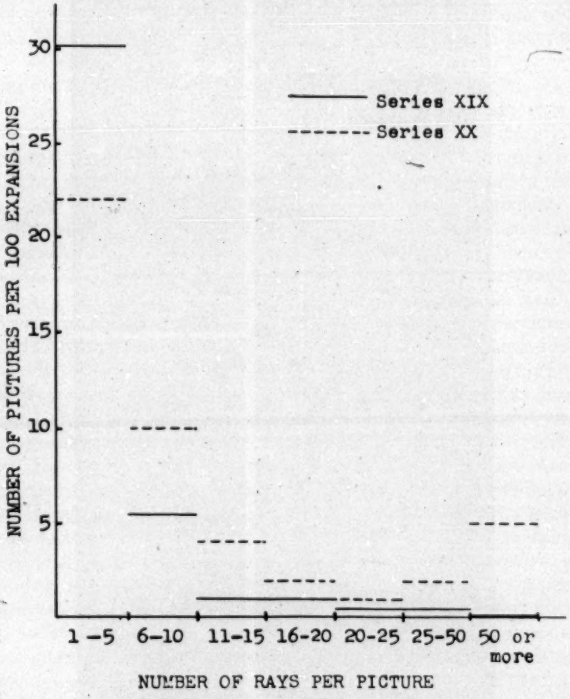
243: shower of 7 high-energy electron tracks, emerging from several centers, and two nuclear tracks. One nuclear track (arrow) is of very short range, and lies completely *in the gas;* its breadth indicates that it was probably formed simultaneously with the electron tracks. The other nuclear track (upper corner of quadrant II) is very old, and is separated by the sweeping field; two of the electron tracks appear to emerge from its point of origin. 38: two simultaneous pre-expansion nuclear tracks from the bottom of the chamber, and a small nuclear track in the central portion (arrows). The longest track has a photographic breadth of 0.2 cm., and a length of 2.3 cm. in the gas. The general fog in the chamber was absent on preceding and succeeding pictures of the sequence.

central plate and the box of the chamber, and was both higher and more symmetrical; no appreciable difference in the distribution or appearance of the nuclear tracks was observed.

Nuclear tracks of the type previously reported [12] have been attributed, by some writers, to old α-particles from radioactive contamination. However, this conclusion was drawn from

observations with other apparatus, controlled by vertically-collinear counters. It is clearly not permissible to assume that cosmic-ray interactions selected by non-collinear counters

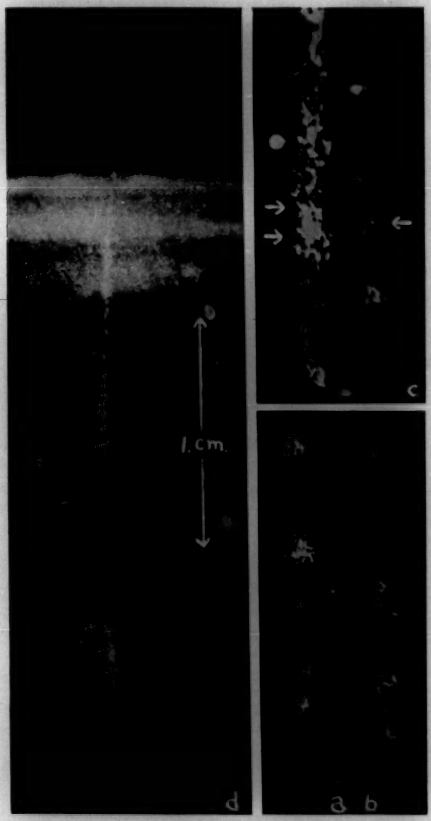
FIG. 13.



Distribution of sizes of showers under lead, selected with 2-counter control (Series XIX), and with 3-counter control (Series XX), respectively.

will be of the same type as those selected by vertically-collinear ones, although many of the "larger" phenomena would be selected by almost any arrangement of controlling counters.

FIG. 14.



Microphotographs of various cosmic-ray tracks. *a* and *b*, tracks suitable for specific ionization determinations; *c*, portion of the close group of rays in 257 (Fig. 9), after partial resolution; *d*, the track shown in 359 (Fig. 10).

Rieder and Hess [13] photographed some nuclear particles in the gas of their chamber, which was operated at a high elevation (2300 m.). Street, Schneider, and Stevenson [14] gave unambiguous evidence that nuclear particles are emitted by some cosmic-ray interactions (bursts), and excellent illustrations of the same phenomenon have been photographed by Anderson and Neddermeyer [15] and by Brode, MacPherson, and Starr.[16]

It appears, however, that the phenomenon described by the writer is, at least in part, essentially different from that described by the other observers, because of its dependence on the presence of, and, apparently, on the nature of, the material *outside* the cloud chamber, whose walls are 4.2 g. cm.$^{-2}$ in thickness. (See Table II.) One must either assume that the nuclear particles emitted by bursts are often of sufficiently high energy to penetrate this great thickness of material, or that nuclear particles are ejected from (smaller) thicknesses of material by the secondary action of some high-energy emission from the burst. The latter assumption seems generally preferable, in view of the observed distribution of the particles, and of the fact that some are entirely in the gas of the chamber.

Of the possible secondary agents that might eject nuclei, neutrons or photons would require the least energy to give recoil nuclei of any assigned ranges. This fact, and the resemblance of the nuclear tracks in the gas to neutron-recoils, led the writer to the belief that the secondary agents were neutrons.[17] We now know that quanta of a few millions of volts energy can likewise eject neutrons, by the photo-nuclear effect, and the presence of numerous positron-electron pairs, evidently ejected by high-energy quanta, in some showers, is now a matter of general observation in cloud photographs. Moreover, it is not unlikely that electronic particles may eject some of the observed nuclei, although nuclear tracks that are completely in the gas could not have arisen from ionizing particles. So it is not easy to establish the identity of the particle or quantum responsible for any individual nuclear track,

[13] F. Rieder and V. F. Hess, *Nature*, **134**, 772 (1934).

[14] *Loc. cit.*, reference 4.

[15] *Loc. cit.*, reference 2.

[16] *Loc. cit.*, reference 5.

[17] G. L. Locher, *Phys. Rev.*, **44**, 779 (1933); and JOUR. FRANK. INST., **216**, 673 (1933).

nor is it possible to say that all of the nuclear tracks of cosmic-ray origin are produced by one kind of agent or process.

Figures 10, 11, and 12 show some nuclear tracks that seem to have particular interest. No. 488 shows a dense track traversing the entire chamber. The fog in the chamber, like that in No. 38, is absent in preceding and succeeding pictures. Several pictures of showers have been collected, in which the electronic tracks are so numerous that the chamber appears to be completely filled with fog. It is not possible to tell whether or not the fog is of this type, in the present cases.

The track shown in No. 359 seems of exceptional interest. It is a post-expansion track which gains in density too rapidly to be that of an electron, and its upper portion is too thin to be the track of a proton. (See microphotograph, Fig. 14, *d*.) The curvature at the top is probably due to thermal turbulence at the top of the chamber. There is no reason to believe that the particle that produced this track had anything to do with the expansion, i.e. its photography was accidental. The rapid increase in specific ionization from electronic to nuclear orders suggests that the picture may be an end-of-range example of the "heavy electron" of the type discovered from energy-loss experiments of Street and Stevenson [18] and of Neddermeyer and Anderson.[19]

Among the nuclear tracks seen in controlled photographs, there are many which have relatively large diameters. The question presents itself as to whether these tracks are formed by old α-particles that passed through the chamber long before the expansion and were spread by diffusion and by the sweeping field, or by particles that passed through at the appropriate time, just before the expansion. In the latter case, an explanation should be found for their large diameters and volumes. The frequency of their appearance on controlled pictures, as compared with their frequency on random pictures, indicates that part of these tracks must result from cosmic-ray interactions, although some are unquestionably old α-tracks. Several factors control the observed breadth of a track: (1) the specific ionization of the particle causing the track; (2) the time between the passage of the ray through the

[18] J. C. Street and E. C. Stevenson, *Phys. Rev.*, **51**, 1005A (1937).

[19] S. H. Neddermeyer and C. D. Anderson, *Phys. Rev.*, **51**, 884 (1937).

chamber and the growth of the drops to a "critical" size; (3) the presence or absence of a trace of electronegative gas or vapor in the cloud atmosphere; and (4) the magnitude, distribution, and instant of removal, of the sweeping field in the chamber. Of these, (4) has been discussed, as it concerns these investigations. In regard to (3), no electronegative substance was deliberately put into the cloud atmosphere for the purpose of electron attachment, but it is almost certain that sufficient water and oxygen are present for this purpose, since the cloud chamber could not be completely dried and degassed before filling. The agreement of the observed breadths of electron tracks with breadths computed from Blackett's formula is an independent and sufficient proof of the approximate equality of mobilities of the positive and negative ions, hence of electron attachment in $\ll 0.01$ sec.

The assumption that artificial radioactivity is induced in material about the cloud chamber, by large cosmic-ray interactions, would fulfill the time requirements for the formation of thick nuclear tracks. For one has only to suppose that, as in known nuclear reactions involving the emission of nuclear particles, the nuclear particles are emitted instantaneously, and the γ- and/or β-emission follows. On this view, the large diameters of observed nuclear tracks would result from their diffusion during the lives of the activated atoms. There can be little doubt that cosmic-ray interactions must occasionally lead to the production of artificially-radioactive atoms, and it may be expected that this kind of radioactivity can be detected, on rare occasions, or under experimental conditions that are especially favorable to its detection. One would scarcely expect the emission of one or two nuclear particles (from one point) to be followed by the radioactive emission of a large shower of photons or electrons, but the emission of one or two photons and/or electrons may be expected. Since cosmic-ray interactions involve very high energies, great caution must be used in extrapolation of knowledge of nuclear reactions produced in elements mostly of low atomic number by the relatively low-energy emissions from high-voltage machines, to reactions produced in elements mostly of high atomic number by cosmic rays. One naturally expects the latter to be less frequent and more complex. While some of

the thick nuclear tracks may conveniently be explained by cosmic-ray-induced radioactivity, the experimental data are yet too few to make this explanation more than tentative.

One must also consider the possibility that some of the thick nuclear tracks from the walls might be due to particles that passed through the chamber immediately before the expansion, but whose minimum track diameters are inherently larger than could be accounted for by the time of expansion of the apparatus and the specific ionization of ordinary heavy particles. The explanation of their large volumes, suggested by W. F. G. Swann,[20] is essentially as follows: If the particles making these tracks are recoil nuclei of heavy elements, and if they are given very large momenta by high-energy neutrons, their charges could be as high as Ze, where Z is the atomic number of the nucleus considered. Since the specific ionization is proportional to Z^2e, a track of a completely ionized nucleus of, say, $Z = 18$, would presumedly have a specific ionization 81 times that of a doubly-charged α-particle. Its range, for a given energy, would be greatly reduced because of the rapid loss of energy by ionization. Near the end of its range, such a particle would, of course, acquire electrons, and its specific ionization would correspondingly decrease; so the track should be shaped like a raindrop, the *thin* portion of the drop corresponding to the *end* of the range of the particle. The broadness of such tracks would result from two things: (1) the high specific ionization, and (2) the very numerous delta-rays along the track. On the classical Thomson theory,[21] the energy Q given to an electron by an impinging particle is $Q = 2mV^2f^2/(p^2 + f^2)$, where $f = Ze^2/mV^2$, p is the impact parameter, e and m are electronic charge and mass, and V is the velocity of the impinging particle. The maximum energy given to an electron is, thus, independent of Z; but the number of electrons (delta-rays) whose energy exceeds any value $Q_i < 2mV^2$ is proportional to Z^2. Unfortunately, no information about the rate of gain of charge by highly-ionized

[20] This interpretation was suggested to the writer by W. F. G. Swann, in December 1933 (reference 12). Blackett also mentions that it was proposed at the Solway Conference, Brussells, October 1933 (reference 9).

[21] Thomson, "Conduction of Electricity through Gases," Vol. 2, Cambridge Univ. Press, 1933.

nuclear particles is available. The writer considers this a possible explanation of some of the observed broad tracks, but does not propose that it is the only tenable one.

Nuclear Tracks in the Gas.

Short nuclear tracks which are completely in the gas, (illustrated by No. 243, Fig. 12), have previously been attributed to atoms of the gas recoiling under elastic collisions with neutrons generated by cosmic-ray bursts.[17] The high ion-density of these tracks leaves no doubt that they are made by nuclear particles. The belief that these particles were neutron-recoils was based on the similarity of their tracks to recoil tracks produced by neutrons from a weak Po-Be source, in the same cloud atmosphere. When the observations were first reported (1933), the photo-nuclear effect of gamma-rays [22] had not yet been discovered, so that neutrons were the only non-ionizing agents that were known to eject unaccompanied nuclear particles in gases. Now, however, we must add the possibility that some are made by atoms of the gas (argon) recoiling from the *ejection* of neutrons by high-energy gamma-radiation emitted by the bursts or showers, i.e. recoil parent-atoms from photo-nuclear effect in the gas. In either case, it seems necessary to suppose that the tracks are of recoil atoms from interactions involving neutrons: in the first instance, the neutrons are liberated from material near the cloud chamber (by photo-nuclear effect, or by other disintegrations), and, in the second, the very hard gamma-rays eject neutrons from atoms of the gas, which thereby recoil along the observed tracks.[23]

Small spherical clusters of ions, like those in No. 247, Fig. 11, are sometimes seen on controlled photographs. The smallness of their energy makes it impossible, in many cases,

[22] Szilard and Chalmers, *Nature* 134, 494 (1934); J. Chadwick and M. Goldhaber, *Proc. Roy. Soc.*, A151, 479 (1935).

[23] The neutrons recorded with photographic plates under paraffin, in the stratosphere (L. H. Rumbaugh and G. L. Locher, *Phys. Rev.*, 49, 855 (1936), and National Geog. Soc'y. Contributed Technical Papers, Stratosphere Series, No.2), are almost certainly due to a neutron component in the *primary* cosmic radiation. Most of the tracks similarly recorded on Pikes Peak, and those photographed by Anderson and Neddermeyer (reference 2), on Pikes Peak, are probably also due to the primary cosmic-ray neutrons.

to tell whether they are produced by nuclei or by electrons. Tracks of this type were not included as "nuclear tracks," in the data given in Table II. While some of them may be recoil nuclear particles of the types mentioned above, they may equally well be recoil electrons ($<$ 10,000 volts) from γ-ray scattering, or photoelectrons from the soft Auger x-rays produced along the paths of other ionizing particles.

These investigations are being continued with an arrangement similar to that shown in Fig. 1-*B*, but with the material M below the cloud chamber and counters, instead of above. Comparison of the numbers of post-expansion tracks on controlled and on random pictures made with this arrangement should be a more sensitive test for possible cosmic-ray-induced radioactivity than that described above. No. 1060, Fig. 6, was made with the arrangement just described.

The writer is indebted to Dr. W. F. G. Swann and to Dr. Arthur Bramley for discussions of the phenomena described in this paper.

THE REFRACTIVITY INTERCEPT AND THE SPECIFIC REFRACTION EQUATION OF NEWTON. II. THE ELECTRONIC INTERPRETATION OF THE REFRACTIVITY INTERCEPT AND OF THE SPECIFIC REFRACTION EQUATIONS OF NEWTON, EYKMAN AND LORENTZ-LORENZ.

BY

S. S. KURTZ, JR.,* AND A. L. WARD.†

I. INTRODUCTION AND ABSTRACT.

In the first part of this paper [1] the linear relation between the refractive index $\left(n\frac{20}{D}\right)$ and density $\left(d\frac{20}{4}\right)$ of hydrocarbons in the liquid state, at constant temperature and pressure, was discussed, and a new constant called the "refractivity intercept" $\left(n-\frac{d}{2}\right)$, based upon this linear relation between n and d for various homologous series, was defined. It is reasonable to investigate the fundamental physical causes of this linear relation. In view of the known close relation between refraction, dispersion and the electronic oscillators in organic molecules, it is furthermore reasonable to calculate the number and characteristic frequency of "dispersion electrons" in various types of hydrocarbons to see what light these data can throw on this subject.

Two types of dispersion equations are available for such calculations, namely, the Sellmeier-Drude type equation [2, 3, 4, 5, 9] in terms of n^2-1 and the Lorentz-Lorenz

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[1] S. S. Kurtz, Jr. and A. L. Ward, J. FRANKLIN INSTITUTE, 222, 563, 1936.

[2] W. Sellmeier, *Pogg. Ann.*, 143, 272 (1871); 145, 399 and 520 (1872); *Pogg. Ann.*, 147, 386 and 325 (1872).

[3] P. Drude, *Annalen der Physik*, 14, 677–725, 1904.

[4] F. K. Richtmyer, "Introduction to Modern Physics," McGraw-Hill, New York, 1928.

[5] R. A. Houstoun, "A Treatise on Light," pp. 423–425, Longsmans, Green & Co., London, 1930.

type equation [6, 7, 8, 9, 10] in terms of $n^2 - 1/n^2 + 2$. It is, therefore, necessary to choose between these two types of dispersion equations.

The data presented in the first part of this paper [1] show that for isomeric paraffins the Newton specific refraction equation

$$\frac{n^2 - 1}{d} = \text{constant}, \tag{1}$$

more accurately represents the relation between density $\left(d\frac{20}{4}\right)$ and refractive index $\left(n\frac{20}{D}\right)$ than the Lorentz-Lorenz specific refraction equation

$$\frac{(n^2 - 1)}{(n^2 + 2)}\frac{1}{d} = \text{constant}. \tag{2}$$

As will be seen later, this is evidence in favor of using the Sellmeier-Drude form of dispersion equation, but in view of the widespread belief that the Lorentz-Lorenz equation has a very sound theoretical derivation, and that it is a universal relation independent of both temperature and pressure, it is desirable to investigate the evidence for and against the Lorentz-Lorenz equation most carefully before making a final choice of the proper dispersion equation to use in correlating data for hydrocarbons. Because of the Maxwell relation

$$n^2 = \epsilon \tag{3}$$

it is also necessary to consider evidence for and against the Clausius-Mosotti [11, 12] equation

$$\frac{(\epsilon - 1)}{(\epsilon + 2)}\frac{1}{d} = \text{constant}, \tag{4}$$

[6] H. A. Lorentz, *Annalen der Physik*, 9, 641, 1880.

[7] L. Lorenz, *Annalen der Physik*, 11, 70, 1880.

[8] H. A. Lorentz, "Theory of Electrons," p. 147. B. G. Teubner, Leipzig, 1909.

[9] K. L. Wolf and K. F. Herzfeld, p. 480, Vol. XX of Handbuch der Physik, Edited by H. Geiger and K. Scheel; published by Springer, Berlin, 1928.

[10] W. Hückel, "Theoretische Grundlagen der Organischen Chemie," Vol. II, pp. 55–64. Akademische Verlags Gesellschaft, Leipzig, 1931.

[11] R. Clausius, "Die Mechanische Warmetheorie," Vol. II of "Die Mechanische Behandlung der Electricitat," pp. 71, 72, 93, 94. Viewig, Braunschweig 1879.

[12] P. Debye, "Polar Molecules," pp. 11, 12, 13 and 36. Chemical Catalogue Co., New York, 1929.

since experimental data supporting either the Lorentz-Lorenz or Clausius-Mosotti equation tends to substantiate the other.

It must be emphasized that we are primarily interested in the relation between refractive index and density for hydrocarbons in the liquid state at 20° C. and atmospheric pressure. It seems logical to work out the relation between these properties at constant temperature and pressure and then to study the effect of varying temperature and pressure.

In 1879–80, when Clausius and Lorentz were first publishing their equations, molecules were thought of as incompressible spheres in kinetic motion. With this physical picture, it was reasonable to assume that the refracting power of each sphere would be independent of temperature and pressure since the latter variables would affect only the packing of the spheres and, therefore, the bulk density of the matter. Much emphasis was, therefore, placed upon the fact that the constants of the Lorentz-Lorenz and Clausius-Mosotti equations were approximately independent of temperature and pressure. In investigating the validity of these two equations for liquid hydrocarbons, it is consequently necessary to consider the effect of temperature and pressure on refractive index, dielectric constant, and density.

This investigation brings out the fact that experts in this field[13, 14, 15, 16], including Lorentz himself,[6] have long recognized a small systematic deviation of refraction data for liquids from the Lorentz-Lorenz equation with change in temperature. This equation specifies too large a change in refractive index for a given increment of density when refractive index and density change due to changing temperature, i.e., using the notation of the first part of this paper,[1] the slope (equation (5))

$$\left[\frac{\Delta n_c}{\Delta d_c}\right]_{t_1}^{t_2} = \text{Slope} \tag{5}$$

[13] J. F. Eykman, *Rec. Trav. Chim.*, 14, 185, 1895.

[14] W. Nernst, "Theoretical Chemistry," p. 314. MacMillan Co., London, 1911.

[15] F. Eisenlohr, "Spechtrochemie Organischer Verbindungen." F. Enke, Stuttgart, 1912.

[16] J. C. Vlugter, H. I. Waterman and H. A. van Westen, *J. Inst. Pet. Tech.*, Vol. XXI, p. 665, 1935.

predicted by the Lorentz-Lorenz equation is too large. Furthermore, it is found that equations in the Eykman form [13]

$$\frac{(n^2 - 1)}{(n + 0.4)} \frac{1}{d} = \text{constant} \tag{6}$$

and

$$\frac{(\epsilon - 1)}{(0.4 + \sqrt{\epsilon})} \frac{1}{d} = \text{constant} \tag{7}$$

usually represent the effect of temperature or pressure on density and either refractive index or dielectric constant, respectively, within the limit of experimental error.

Empirical evidence is, therefore, against the validity of the Lorentz-Lorenz and Clausius-Mosotti relations for non-polar liquids.

Examination of the derivation of the Lorentz-Lorenz dispersion equation [8, 9, 12] and of the Sellmeier-Drude dispersion equation [3, 5, 9] reveals that the difference between these two equations depends upon the attempt in the case of the Lorentz-Lorenz equation to evaluate the internal field strength in a dielectric on the assumption that the molecules in an electrostatic field between condenser plates contribute to the total field between the plates. Both Lorentz [8] and Debye [12] recognize that the evaluation of this "internal field strength" involves an assumption which it is difficult to justify, namely, discarding entirely one of the three components created for the evaluation of the internal field strength. Evaluation of this third component in a simple reasonable manner indicates that it is opposite in sign but almost equal in magnitude to the second component, so that only the first component, the normal field strength, remains. In other words, the accepted derivation of the Lorentz-Lorenz and Clausius-Mosotti equations is incorrect, and the Sellmeier-Drude dispersion equation, which is equivalent to the Newton specific refraction equation, is the only one which can be derived in the classical manner from the electromagnetic theory of light and the assumption that the dispersion electrons act as linear harmonic oscillators.

By inserting in the Sellmeier-Drude dispersion equation a coefficient for the change of frequency of the dispersion electrons with change in temperature it is possible to obtain an

equation which agrees with the empirical but exact Eykman equation for the effect of temperature.

The Sellmeier-Drude form of dispersion equation, therefore, seems adequate for the study of refractive index and density data of hydrocarbons, especially since the modern dispersion equations based on wave mechanics show that refractive index has the same form of relation to frequency as in the Sellmeier-Drude equation. The latter equation is used for correlation of data because of its relative simplicity.

Application of the Sellmeier-Drude dispersion equation to data for the isomeric heptanes reveals that the number and frequency of the dispersion electrons are constant for all the isomeric heptanes and that there are 1.066 apparent dispersion electrons per formula bond. Since there are in all probability two valence electrons per formula bond this perhaps means that the f coefficient in the wave-mechanics equation for dispersion [10] is approximately 0.533. This coefficient is primarily dependent on the probability of transition between two energy states; the relation seems to hold, at least approximately, for all single carbon-carbon or carbon-hydrogen bonds. In the case of double bonds, the probability of transition is so small or the absorption bond is so far in the ultraviolet that the valence electrons in the double bond apparently do not contribute to the dispersion effects in the visible spectrum.

Interpretation of the refractivity intercept on the basis of number and frequency of dispersion electrons shows that the main difference between naphthenes and paraffins is in the number of dispersion electrons per unit volume, not in their frequency of vibration. In the case of aromatics both the number of dispersion electrons per milliliter and their frequency is less than for saturated cyclics, but the decrease in characteristic frequency is so great that a high refractive index results.

It is shown that in the paraffin homologous series there is a change in characteristic frequency with increasing molecular weight if a constant factor is used for the number of dispersion electrons per formula bond. Further work will be required to establish definitely whether it is the apparent *number* of dis-

persion electrons per bond or their *frequency* which varies as we ascend the paraffin homologous series.

Although this investigation was undertaken to obtain a better understanding of the refractivity intercept, and is successful in this respect, an equally valuable positive contribution of the paper is the conclusive evidence for the validity of the Eykman equation for the effect of temperature and pressure on refractive index or dielectric constant and for the Sellmeier-Drude type of dispersion equation. The most important negative contribution of the paper is the proof that the Lorentz-Lorenz equation is invalid.

II. EQUATIONS AVAILABLE FOR CORRELATING REFRACTIVE INDEX AND DENSITY DATA WITH THE ELECTRONIC PROPERTIES OF MOLECULES.

The Sellmeier-Drude *[2, 3, 4, 5] and Lorentz-Lorenz [6, 7, 8, 9, 10] forms of dispersion equations relating refractive index and density to the electronic properties of molecules are given in Table I. All these equations depend upon the concepts of classical physics, therefore, one might well hesitate to expend much effort on the application of these equations to data for organic compounds, if it were not for the fact that the experts in this field, in general, agree that the dispersion equations based upon quantum mechanics have the same form of de-

* Drude [3] wrote the equation in a form, equivalent to

$$(18) \qquad p\frac{e}{m_0} = 3.26 \times 10^{-4}\frac{M}{d}\left(\frac{1}{\lambda_1^2}-\frac{1}{\lambda_2^2}\right)\frac{(n_1^2-1)(n_2^2-1)}{(n_1^2-n_2^2)}.$$

This equation is obtained from equation (16) by first substituting p for bk and c/λ for v, where p = number of dispersion electrons per molecule, c = the speed of light = 2.9986×10^{10} cm./sec.; and λ = wave-length of light in cm.; then writing the equation for two wave-lengths of light λ_1 and λ_2 and finally eliminating λ_0. Drude preferred to solve for $p\frac{e}{m_0}$ because at that time the value of the ratio e/m_0 was not definitely established. He expressed the ratio e/m_0 in electromagnetic units and the right-hand side of equation (18) in electrostatic nits, therefore, the constant 3.26×10^{-4} in the equation is equivalent to $\frac{\pi c}{eA}$. Using the modern value in electromagnetic units for e/m_0, namely, $e/m_0 = 1.769 \times 10^7$ one may write

$$(19) \qquad p = 1.840 \times 10^{-11}\frac{M}{d}\left(\frac{1}{\lambda_1^2}-\frac{1}{\lambda_2^2}\right)\frac{(n_1^2-1)(n_2^2-1)}{(n_1^2-n_2^2)}$$

and this equation has been used in calculating the value of p from the data of Erfle [40] (vide infra).

pendence upon frequency as do the equations given in Table I. Van Vleck [17] and Schutz [18] give wave mechanics equations equivalent in general form to equation (14), whereas Hückel (Ref. 10, p. 77) gives an equation which is similar in general

TABLE I.

Equations Relating Refractive Index and Density to the Electronic Properties of Molecules.

Type.	Equations in the Sellmeier-Drude Form.*		Equations in the Lorentz-Lorenz Form.†	
	Equation No.		Equation No.	
One term simple dispersion equation	8	$n^2 - 1 = \left[\frac{B}{V_0^2 - V^2}\right]$	11	$\frac{n^2-1}{n^2+2} = \frac{1}{3}\left[\frac{B}{V_0^2 - V^2}\right]$
	9 10	$B = Ne^2/\pi m_0$ $N = [(d/M)Abk]$ $= [(d/M)Ap]$		
Two term simple equation	12	$n^2 - 1 = \left[\frac{B_1}{V_{1_0}^2 - V^2} + \frac{B_2}{V_{1_0}^2 - V^2}\right]$	13	$\frac{n^2-1}{n^2+2} = \frac{1}{3}\left[\frac{B_1}{V_{1_0}^2 - V^2} + \frac{B_2}{V_{2_0}^2 - V^2}\right]$
"Number of electrons" form of equation	14	$n^2 - 1 = \left[\frac{Ne^2}{\pi m_0(V_0^2 - V^2)}\right]$	15	$\frac{n^2-1}{n^2+2} = \frac{1}{3}\left[\frac{Ne^2}{\pi m_0(V_0^2 - V^2)}\right]$
Specific refraction form of equation	16	$\frac{n^2-1}{d} = \frac{Abk}{M} \times \left[\frac{e^2}{\pi m_0(V_0^2 - V^2)}\right]$	17	$\frac{n^2-1}{n^2+2}\frac{1}{d} = \frac{1}{3}\frac{Abk}{M} \times \left[\frac{e^2}{\pi m_0(V_0^2 - V^2)}\right]$
	1	$\frac{n^2-1}{d}$ = Constant of Newton Equation	2	$\frac{n^2-1}{n^2+2}\frac{1}{d}$ = Constant of Lorentz-Lorenz Equation

* See previous footnote.

† The notation used in Equation (17) differs from that used by Wolf and Herzfeld as follows: Our $N = Np$ in Wolf and Herzfeld notation; we have used $2V$ rather than ω and the term containing $i\omega$ has been omitted since it is not intended to discuss affects close to an absorption band.

[17] J. H. van Vleck, "The Theory of Electric and Magnetic Susceptibilities," pp. 15, 16 and 54. Oxford University Press, 1932.

[18] B. Schutz, Quoted by F. Kohlrausch, "Praktische Physik," pp. 843–4. B. G. Teubner, Leipzig, 1935.

TABLE II.

Summary of Derivation of the Specific Refraction Formulae of Newton, and of Lorentz and Lorenz and of the Clausius-Mosotti Equation for Dielectric Constant.

Equation No.	Both Drude and Lorentz.
21	$\epsilon = n^2 = 1 + 4\pi\frac{I}{E}$
21a	$\epsilon - 1 = n^2 - 1 = 4\pi\frac{I}{E}$
22	$I = NI_0 = NeX_0$
23	$I = Na_0eE_d$

Equation No.	Drude.	Equation No.	Lorentz.
25	$E_d = E_v$	27	$E_d = E_v + \frac{4\pi I}{3}$
28	$I = Na_0eE_v$	29	$I = Na_0e\left(E_v + \frac{4\pi I}{3}\right)$
30	$n^2 - 1 = 4\pi Na_0e$	31	$I = \frac{E_v(n^2-1)}{4\pi}$
		32	$n^2 - 1 = \frac{4\pi Na_0e}{E_v} \times \left[E_v + \frac{4\pi}{3}E_v\frac{(n^2-1)}{4\pi}\right]$
		33	$n^2 - 1 = 4\pi Na_0e\left[1 + \frac{(n^2-1)}{3}\right]$
		34	$n^2 - 1 = \frac{4\pi Na_0e}{3}(n^2+2)$
		35	$\frac{n^2-1}{n^2+2} = \frac{4\pi}{3}Na_0e$
36	$n^2 - 1 = \frac{dAp}{M}4\pi a_0e$	37	$\frac{n^2-1}{n^2+2} = \frac{dAp}{M}\frac{4\pi}{3}a_0e$
38	$\frac{n^2-1}{d} = \frac{Ap}{M}4\pi a_0e$	39	$\left(\frac{n^2-1}{n^2+2}\right)\frac{1}{d} = \frac{Ap}{M}\frac{4\pi}{3}a_0e$
40	$\frac{n^2-1}{d} = \frac{Ap}{M}\frac{e^2}{\pi m_0(V_0^2 - V^2)}$	41	$\left(\frac{n^2-1}{n^2+2}\right)\frac{1}{d} = \frac{1}{3}\frac{Ap}{M}\frac{e^2}{\pi m_0(V_0^2 - V^2)}$
1	$\frac{n^2-1}{d}$ = Constant of Newton	2	$\left(\frac{n^2-1}{n^2+2}\right)\frac{1}{d}$ = Constant of Lorentz and Lorenz
		4	$\left(\frac{\epsilon-1}{\epsilon+2}\right)\frac{1}{d}$ = Constant of Clausius and Mosotti

SYMBOLS USED IN TABLES I AND II.

n = refractive index,
V = the frequency of light = $\frac{2.9986 \times 10^{10} \text{ cm. sec.}^{-1}}{\text{wave-length in cm.}} = \frac{C}{\lambda}$,
V_0 = the characteristic frequency of the dispersion electrons,
m_0 = the mass of a dispersion electron = 8.999×10^{-28} g.,
e = the charge of a dispersion electron = 4.774×10^{-10} e.s.,
N = the number of dispersion electrons per milliliter = $1.2403 \times 10^{-5} B$,
d = density in grams per milliliter,
M = the molecular weight,
A = Avogadro's constant = 6.061×10^{23},
b = the number of formula bonds per molecule (either $C - C$ or $C - H$),
k = the number of apparent dispersion electrons per formula bond,
p = the number of apparent dispersion electrons per molecule,
ϵ = dielectric constant,
I = Polarization = electric moment per unit volume,
E = Field strength = force exerted by field on unit charge,
E_v = Field strength in a vacuum,
E_d = Field strength in a dielectric,
I_0 = Polarization or electric moment of one dispersion electron,
X_0 = Displacement of a dispersion electron from equilibrium,
$a_0 = \frac{X_0}{E}$ = Polarizability of one dispersion electron.

form to equation (15). The frequency and density dependence is similar in each case, but the $n^2 - 1$ or $(n^2 - 1)/(n^2 + 2)$ refractive index term is used as dictated by the preference of the author in question.

The significance of these wave mechanics equations will be discussed in more detail later. At present it is sufficient to state that the authors have found it practical to calculate the number and frequency of dispersion electrons, using equations such as given in Table I, and then interpret these data in the light of the wave mechanics equations. It is, therefore, necessary to choose between the Sellmeier-Drude and Lorentz-Lorenz forms of refraction equations before undertaking a series of such calculations.

It is clear from inspection of equations (8) and (11) that if refractive indices are available for two frequencies of light, such as the alpha and beta lines of the hydrogen spectrum, that it will be possible to set up simultaneous equations and solve for V_0. With V_0 available B or N can be calculated. If refractive indices for four spectral lines are available one can attempt to solve two term equations such as (12) and (13), but there is little point in doing this because the data now available are restricted to the visible spectrum so that the range of frequencies available is not great enough to provide

a satisfactory solution of the two term equation; at least this is true in the case of hydrocarbons for which V_0^2 is about 10 times as large as V^2 for any line in the visible spectrum.

It is worth mentioning that in the case of gases it is frequently recommended (Ref. 12, Chapters I and III) that the Lorentz-Lorenz equation (2) be modified by assuming that $n^2 + 2 = 3$. If this assumption is made it is clear that equations (8) and (11) would become identical since 3 would cancel out on each side of equation (11). In other words as n^2 approaches 1 as a limit the Lorentz-Lorenz equation approaches the Sellmeier-Drude equation as a limit. In general the resort to data for gases in testing refraction equations is unsatisfactory because of the small difference between n and 1.000 in gases unless under high pressure.[19] In spite of this difficulty data for gases are frequently referred to (for example, reference 17, p. 15) as establishing the validity of the $n^2 - 1/n^2 + 2$ form of equation. Data in regard to this point will be presented later.

The primary purpose of this study is to obtain a better understanding of the significance of the refractive index of hydrocarbons in the liquid state. It was shown in the first part of this paper that the Newton specific refraction equation (which is a restricted form of the Sellmeier-Drude dispersion equation) did accurately represent the relation between the density and refractive index of the isomeric heptanes at constant temperature and pressure. This is evidence in favor of the use of the Sellmeier-Drude refraction equation.

Before discarding the Lorentz-Lorenz type equation its derivation will be carefully considered, and it will be tested with a variety of experimental data to see whether or not there is any type of experimental data which the Lorentz-Lorenz equation can correlate more accurately than the other available refraction equations.

III. DERIVATION OF THE SELLMEIER-DRUDE AND LORENTZ-LORENZ REFRACTION EQUATION FROM THE FUNDAMENTAL ELECTROSTATIC FIELD RELATIONS.

(1) *Electrostatic Field Relations.*

The treatment of electrostatic field relations here given is based upon the discussion of Lorentz,[8] Debye [12] and Wolf and

[19] H. O. Jenkins, *Trans. Faraday Soc.*, 30, 752, 1934.

Herzfeld.[9] The notation system, in so far as possible, is that of Debye.

The specific inductive capacity or dielectric constant is defined as the ratio of the capacity of a condenser with a dielectric between its plates to the capacity of the same condenser with a vacuum between its plates, i.e.

$$\epsilon = \frac{C_d}{C_v}, \tag{20}$$

ϵ = dielectric constant,
C_d = capacity of condenser containing dielectric,
C_v = capacity of some condenser having vacuum between plates.

According to Maxwell's electromagnetic theory of light

$$\epsilon = n^2. \tag{3}$$

It is experimentally demonstrable that

$$\epsilon = 1 + 4\pi\frac{I}{E}, \tag{21}$$

where E is the field strength and I is defined as the "Polarization" per unit volume V. The idea is that every element dV acts as if it were the seat of an electric moment equal to IdS.

In the case of non-polar compounds such as saturated hydrocarbons, it has been shown experimentally that there is practically no tendency for orientation in an electric field, therefore, the polarization is all attributable to the electrons (dispersion electrons) which take up forced vibrations in the electrostatic field. If an electron (charge = e) is displaced a distance x_0 from its position of equilibrium the electronic polarization $I_0 = ex_0$ (Ref. 9) and if there are N dispersion electrons per milliliter, then the polarization, i.e., the electric moment of this ml. of dielectric will be given by the equation

$$I = NI_0 = Nex_0. \tag{22}$$

The displacement x_0 divided by the field strength E is defined as the polarizability (a_0) and the charge e multiplied

* The 4π in this equation follows from the definitions of the units used. Heaviside and Lorentz (Ref. 8, p. 2) advocated the use of units which would eliminate most of the 4π factors in electrical equations.

by the field strength is defined as the force (F) on the electron, therefore one may write

$$I = N(eE_d)\frac{(x_0)}{(E_d)} = Na_0eE_d, \tag{23}$$

$$I = Na_0F. \tag{24}$$

The field strength E in these equations is the classical field strength defined as the force acting upon a unit charge in the field. Since it is assumed in the classical theory that this force is the same whether the dielectric is present or not one may write

$$E = E_d = E_v, \tag{25}$$

where E_v = the "field strength" between the condenser plates with a vacuum between them
and E_d = the field strength between the condenser plates with the dielectric d between them.

According to the Lorentz point of view equation (25) for the field strength in the dielectric is incorrect, and should be replaced by an equation containing a term E_2 for the effect of the electrons in the dielectric, as shown in equation (26).

$$E_d = E_v + E_2. \tag{26}$$

Lorentz demonstrated (Ref. 8, note 54; Ref. 12, p. 10) that if one consider the force acting on a unit charge in the center of a spherical vacuole in the dielectric as the "internal field strength" then E_2 equals $\frac{4\pi}{3}I$ and one may write

$$E_d = E_v + \frac{4\pi}{3}I. \tag{27}$$

The derivation of equation (27) will be considered in more detail later.

The polarization in the mass of the dielectric is expressed by the equation

$$I = Na_0eE_d, \tag{28}$$

but we have two equations for evaluating E_d. Equation (25)

represents the Sellmeier-Drude point of view whereas equation (23) represents the Lorentz internal field strength point of view.

(2) *Derivation of Specific Refraction Equations.*

The derivations of the Newton specific refraction equation and of the Lorentz-Lorenz specific refraction equation from equation (23) have been summarized in Table II. The derivation consists essentially in substituting the Drude or Lorentz value for E_d in equation (23) and then eliminating I by substituting for that variable in equation (21), or its equivalent, equation (31). Simple algebra then leads to equation (30) in the $n^2 - 1$ form and equation (35) in the $\frac{n^2 - 1}{n^2 + 2}$ form. Substituting the value of N from equation (10) and dividing by d puts the equations in the specific refraction form, $\frac{n^2 - 1}{d}$ and $\frac{(n^2 - 1)}{(n^2 + 2)}\frac{1}{d}$ respectively. The right-hand side of either equation (38) or (39) is in terms of a_0, the polarizability of a dispersion electron.

Calculation on the assumption that the electrons act like linear harmonic oscillators and that Maxwell's field equations are correct leads (Ref. 5 and 9) to equation (42) for the electronic polarizability.

$$(42) \quad a_0 = \frac{e}{m_0(\omega_0^2 - \omega^2 + i\omega v^1)} = \frac{e}{4\pi^2 m_0(v_0^2 - v^2 + \theta)},$$

where $\omega = 2\frac{\pi e}{\lambda} = 2\pi v$,

v_0 = frequency of vibration of electrons,
v = frequency of vibration of light.

In these equations the terms $(i\omega v^1)$ and θ describe effects which are of appreciable magnitude only near an absorption band, therefore, for colorless organic liquids examined in the visible spectrum, $(i\omega v^1)$ and θ both are practically zero. Therefore, one may write

$$(43) \quad a_0 = \frac{e}{4\pi^2 m(v_0^2 - v^2)}.$$

This value of a_0 was substituted in equations (38) and (39) to obtain equations (40) and (41) respectively. For any one wave-length of light the right-hand side of equation (40) and (41) will be constant if v_0^2 and p are constant, hence one may write the specific refraction equations of Newton (1) and of Lorentz (2) in which the constants are evaluated. One should keep in mind the possibility that temperature or pressure may cause a change in v_0^2 or p.

(3) *Critical Consideration of the Internal Field Strength Hypothesis.*

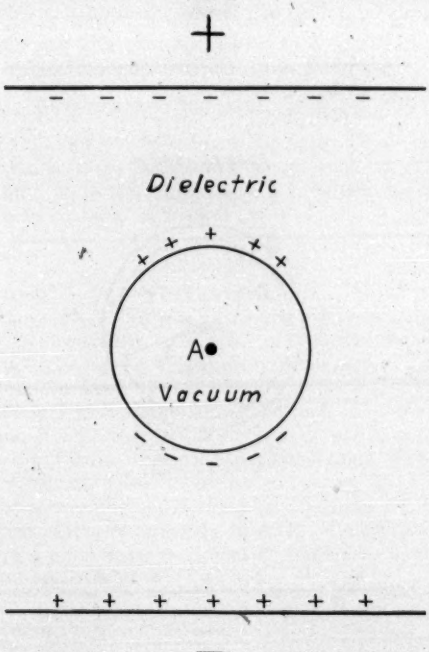
In view of the demonstrable superiority of the Newton and Drude equations over the Lorentz-Lorenz equations when applied to hydrocarbons at a constant temperature and pressure and in the liquid state, it is pertinent to return to the derivation outlined in Table II and consider carefully the point of departure at which the Lorentz derivation begins to differ from the Drude type of derivation.

The point of departure in the derivation of the Lorentz equation is the evaluation of E_d, the field strength acting on an electron in the dielectric, which according to Drude is simply the field strength which occurs in equation (21), whereas Lorentz deduces that it is larger than this by $\frac{4\pi}{3}I$ as shown in equation (27). Wolf and Herzfeld refer to the term $\frac{4\pi}{3}I$ as the "Lorentz-Lorenz force." Consideration of Table II makes it clear that it is only the introduction of this "Lorentz-Lorenz" force, which leads to the $\frac{n^2-1}{n^2+2}$ form of equation. The derivation of equation (27) will therefore be considered in some detail to see if there is any justification for introducing the Lorentz-Lorenz force.

Lorentz (Ref. 8, pp. 137–39 and 303–306) reasons that the electromagnetic field contains components that are due to the individual particles of the system. Therefore, there must be a mutual interaction or effect of these charged particles on one another due to their contribution to the electromagnetic field. To evaluate the forces acting on an electron in the

dielectric he conceives that a particle of matter A, containing an electron, is surrounded by a closed spherical surface, the dimensions of which are infinitely small in a physical sense, and that all particles except particle A are removed from within this sphere, as indicated in Fig. 1.

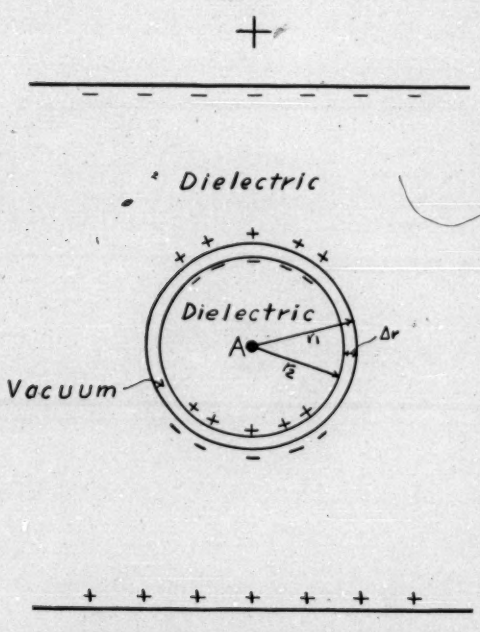
FIG. 1.



There will be a distribution of electricity on the surface of this spherical vacuole due to the polarization of the outside portions of the dielectric, and the force E' exerted by this distribution on a unit charge located at A must be added to the field strength E, which is used in equation (21) above.

Lorentz then considers the effect of re-introducing the matter other than particle A, which he had supposed to be removed, from the sphere. The matter within the sphere is said to exert a force E'' on a unit charge located at A. Therefore,

FIG. 2.



the field strength in the dielectric, E_d, is given by the equation

$$E_d = E_v + E' + E''. \tag{44}$$

The evaluation of E' and E'' is considered in detail by Lorentz in notes 54 and 55, pages 303–306 of reference 8. It is shown that the effect of the charge on the surface of the

spherical cavity makes it possible to calculate E according to the equation

$$E' = \frac{4\pi}{3} I. \tag{45}$$

The next step in the derivation is best presented by quoting Lorentz (Ref. 8, p. 138) "The problem of determining E'' is more difficult. I shall not dwell upon it here, and shall only say that for a system of particles having a regular cubical arrangement, one finds (note 55)

$$E'' = 0, \tag{46}$$

a result that can be applied with a certain degree of approximation to isotropic bodies in general, such as glass, fluids and gases. It is not quite correct, however, for these and ought to be replaced in general by

$$E'' = q\frac{4\pi}{3} I,^* \tag{47}$$

where, for each body, q is a constant which will be difficult exactly to determine." In spite of this discussion Lorentz proceeds to use equation (46) rather than (47) in interpreting E'' in equation (44). Substituting equations (45) and (46) in equation (44) gives equation (27) which as pointed out, is the point of departure in the Lorentz derivation. It is clear that Lorentz is far from confident concerning his evaluation of E''. Debye † (Ref. 12, pages 10, 11, 13, 36) is also quite doubtful concerning the validity of assuming $E'' = 0$. The whole proceeding of equating E_d to $E_v + E' + E''$ and then assigning a finite value to E_v and E' and a zero value to E'' is suspiciously artificial.

* The notations in equation (39) have been modified to conform with the other equations.

† Debye's treatment of the subject as exemplified in his book "Polar Molecules," requires clarification, since he states that E'' is zero when there is no molecular interaction as in a completely non-associated liquid. In view of the evidence of Drude and Erfle that there is a direct connection between valence electrons and refraction and dispersion effects, refraction equations should be concerned primarily with forces *within*, rather than forces *between* molecules. Debye's interest in polar molecules which can orient in an electrostatic field has confused rather than clarified his treatment of non-polar liquids.

A method of evaluating E'' which the authors believe to be accurate within the limits imposed by the physical discontinuity of matter is to imagine in the dielectric a spherical vacuole of finite volume bounded by a spherical surface S_1 (Fig. 2) of radius r_1. Within this spherical vacuole, imagine a second spherical surface S_2 of radius r_2 filled with the dielectric liquid and having the particle A containing a dispersion electron located at its center. Imagine further that $r_1 - r_2$, the difference in radii of the spheres, is very small, say approximately equal to the diameter of a hydrogen atom. If r_1 and r_2 are first taken as very large relative to Δr then the induced charges on S_1 and S_2 will be approximately equal in magnitude, but along any one radius opposite in sign. In this case

$$E' = +\frac{4\pi}{3} I, \tag{48}$$

$$E'' = -\frac{4\pi}{3} I, \tag{49}$$

$$E' + E'' = 0. \tag{50}$$

In order to reduce any effect on the electron at A of the dielectric material within S_2, one may allow r_2 to approach zero as a limit holding Δr constant. As long as there remains a definite physical surface S_2 capable of carrying an induced charge equation (50) will remain true. If r_2 becomes so small that the problem of the physically discontinuous nature of matter becomes important then it is doubtful if there is any justification for trying to solve for either E' or E'' by any method that has yet been published.*

According to this line of reasoning equation (44) reduces to equation

$$E_d = E_v \tag{25}$$

upon substitution of equation (50), and equation (27), which

* A complete theoretical study of the "internal field strength" must provide means for evaluating the effect upon a given electron of neighboring electrons and molecules in the electrostatic field. It is to be hoped that modern physical and statistical methods will lead to a thoroughly satisfactory solution of this problem. Pending such a complete theoretical solution the writers believe that one may safely assume that the difference between the electrostatic field as used by Drude and the true internal field strength is negligible.

is the keystone in the derivation of the Lorentz-Lorenz and Clausius-Mosotti equations, is therefore invalid.

The Lorentz evaluation of the "internal field strength" may also be considered from the modern operational point of view so ably discussed by Bridgeman.[20] This logical method of analyzing scientific concepts directs attention to the nature of the experimental operations by which the concept is given unique significance.

In the case of the Lorentz derivation of the internal field strength there is assumed in the dielectric a spherical vacuole, on the surface of which the charge is distributed. The concept of the spherical vacuole does not serve to emphasize a potential distribution or gradient which is known to exist; it introduces a hypothetical spherical potential distribution. One cannot prove the existence of such a potential distribution in a dielectric by direct experiment; to prove its existence involves carrying out the physical operations necessary to verify the $\frac{(\epsilon - 1)}{(\epsilon + 2)}\frac{1}{d} = \text{constant}$ and $\frac{(n^2 - 1)}{(n^2 + 2)}\frac{1}{d} = \text{constant}$ equations for non-polar dielectrics. The distribution of potential on a hypothetical spherical surface assumed in the Lorentz derivation has no independent verification apart from whatever experimental verification there may be for these equations.

[20] P. W. Bridgeman, "The Logic of Modern Physics," Chapter I and pp. 132 to 150. The MacMillan Co., New York, 1927.

(To be concluded.)

More Light With Less Maintenance.—In mills and factories especially where dust and vapor conditions are bad it is not uncommon to find a lighting fixture with a 500 watt lamp delivering the equivalent of only 100 watts of light after only a few weeks since cleaning. In the *Electric Journal*, Vol. 34, No. 9, there is described a new lighting unit whose light efficiency over the entire maintenance period is very high. This unit, known as the Millite Luminaire, is dust tight and vapor proof, and consists of a deep aluminum reflector finished by the Alzak process, a socket to take a 750 or 1,000 watt incandescent lamp, and a housing of sheet steel covered with a flat glass lens that is sealed against the housing by a ring and gasket arrangement. There are no ventilating louvres; the heat is dissipated wholly by radiation. The lens is made of a new, highly tempered, highly polished glass. It is clear, flat, and heat resisting. The glass has unusual mechanical properties. Supported at the edges, it will withstand the impact of a 1.68 pound ball dropped seven feet. It will support a 200 pound load concentrated at the center. While a sharp blow with a heavy hammer will break the glass, it has the fortunate characteristic of shattering completely into small blunt pieces. The new Millite glass is but a single layer, its unusual mechanical properties resulting from the heat treating process in which the surfaces are held under high tension. In addition, the glass is able to withstand sharp temperature changes. The unit being vapor proof and dust tight, the only maintenance necessary is an occasional wiping of the outer surface of the lens.

R. H. O.

THE PRESSURE DUE TO CORONA IN A CLOSED SPACE.

BY

A. GEMANT, Ph.D., M.D.

1. In measuring the stream-resistance of porous sound-absorbing materials by means of a method utilising a stream of ozone,[1] the author had an opportunity to observe the increase of the static pressure occurring during a corona discharge in a closed space. The phenomenon was first described by E. H. *Warner*,[2] a theoretical explanation, based on the fact of ionisation, being suggested by J. *Kunz*[3] who has called the effect ionisation pressure. Several authors, so *Arnold*[4] and A. M. *Tyndall*[5] have raised doubt with regard to this explanation and could prove that the effect is not due to ionisation, but to the heating effect of the corona current. A recent paper by M. *Radonjitch* and A. *Thoma*[6] arrives at the same conclusion.

The remarkable suddenness of the rise of pressure at the beginning of the corona discharge as compared with the slower rise in a parallel heating experiment by means of resistance wires, induced the author to carry out a few more experiments on these lines.

It has been pointed out that differences in these parallel experiments are to be expected, owing to the presence of the electric wind in a corona discharge which will seriously affect the conditions of heat conduction, upon which, on the other hand, the pressure arrived at must depend.

The purpose of the following measurements was, therefore, to change some of the *external* conditions of heat conduction. If the results obtained could be explained in terms of these

(Communicated from the Engineering Laboratory, Oxford University.)

[1] A. Gemant, *Berl. Akad. Ber.* 1933.

[2] E. H. Warner, *Phys. Rev.*, 8, 285, 1916.

[3] J. Kunz, *Phys. Rev.*, 8, 28, 1916.

[4] Arnold, *Phys. Rev.*, 9, 93, 1917.

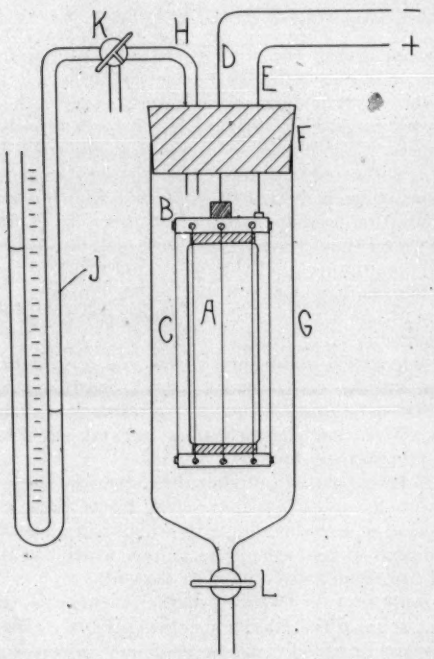
[5] A. M. Tyndall and N. S. Searle, *Phil. Mag.*, 35, 261, 1918.

[6] M. Radonjitch and A. Thoma, *Arch. f. Elektrotechn.*, 29, 692, 1935.

changed conditions, then this was thought to supply a further proof towards the thermal explanation.

2. The experimental arrangement was entirely different from the original co-axial one of Warner and more similar to

FIG. 1.



Corona Device.

that used by the author in a previous investigation on the glow-loudspeaker.[7]

The device is shown in Fig. 1. *A* is a brass cylinder, 3 cm. in diameter and 15 cm. long, kept insulated from the end

[7] A. Gemant, *Physik. Zeits.*, **34**, 158, 1933.

plates B, to which were attached eight wires C, running parallel to the cylinder axis. The wires had a diameter of 0.15 mm., and their distance from the outer cylinder surface was 4 mm. The device was kept in position by means of two stiff wires D, E, serving simultaneously as leads: D to the inner cylinder, E to the wires—both passing through a large rubber stopper F, which fitted into the cylindrical glass container G. A glass tube H was passing through the stopper F and connected the vessel G with the manometer J by means of the three-way stopcock K. At the bottom of the vessel was fitted another stopcock L, connecting G with a small air-pump. The wire D led to the high voltage terminal of a rectifier set, being the negative pole. The wire E led through a milliammeter to the positive earthed terminal of the rectifier set. The manometer contained alcohol, thus making the readings possibly large.

Before applying the voltage, the inner and outer pressure were equalised by means of K. Having applied the voltage and taken the readings from the manometer, both L and K were opened and an air current was blown into the vessel by means of the pump, in order to equalise the inner and outer temperature and to remove any gaseous products of the discharge, like ozone, thus preventing their accumulation in the vessel.

In the parallel heating experiments the resistance wire was wound round the cylinder, so as to give it very nearly the same situation as that occupied by the glow wires. The wire was heated by means of D.C., using a potential difference of a few volts. In both sets the powers were chosen the same, since it was reasonable to assume that in the case of the corona practically the whole energy is transformed into heat and only a very small fraction into work of ionisation, radiation and so on.

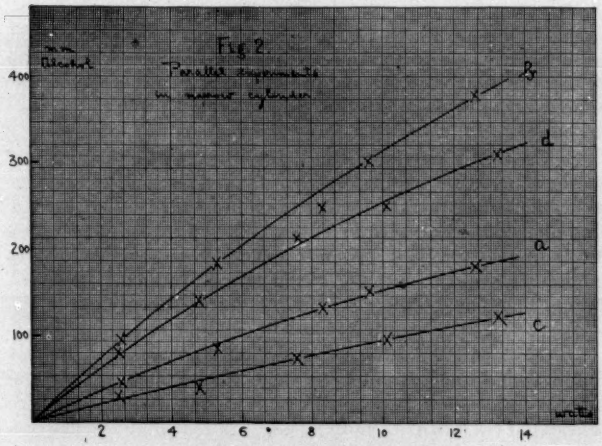
For this purpose the high voltage was measured by means of an electrostatic voltmeter up to 450 volts and a high voltage potentiometer of the liquid resistor type used and described by the author elsewhere.[8] With regard to the low voltage measurement, a voltmeter was applied across the resistance wire

[8] A. Gemant, "Liquid Dielectrics," Wiley, New York, 1933, p. 66.

and an ammeter in series, so a correction for the potential drop in the ammeter had to be considered.

The results carried out with the device shown in Fig. 1 are indicated by the graphs in Fig. 2. The abscissae are the number of watts, the ordinates are the increase of pressure in mm. of alcohol read $2\frac{1}{2}$ minutes after the voltage is switched on. It should be mentioned here that the pressure rises quickly in the first 10 secs. or so, but only gradually in the subsequent

FIG. 2.



Parallel experiments in narrow cylinder.

time, approaching equilibrium very slowly. Curve *a* in Fig. 2 refers to the corona experiments, curve *b* to the thermal one. It can be seen that the pressures are of the same order, the latter being roughly twice as high as the former. Placing now the vessel in a large container of water, heat conduction is facilitated and both curves drop to a certain extent as shown by curves *c* and *d* for the corona and thermal measurements. If a measurable part of the corona effect were due to a specific ionisation effect, immersion into a water bath ought not to have any considerable effect.

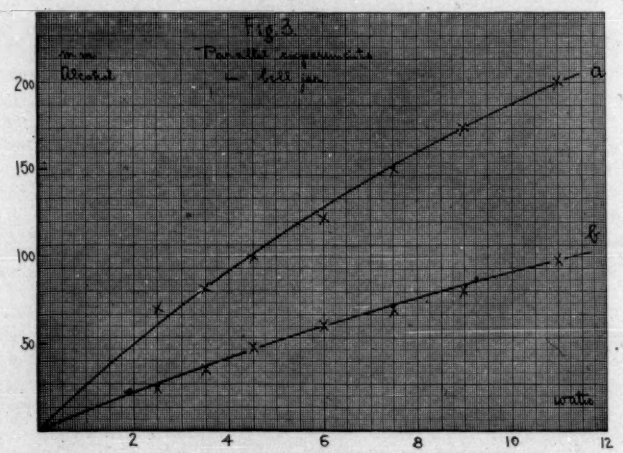
The results indicated in Table I show the sensitivity of the effects to small variations in the arrangement. A corona

TABLE I.

Sensitivity of Effect to Small Changes of Conditions (mm. of Alcohol Against Watts).

Watts.	Corona.		Resistance Wire.	
	Normal Condition.	Asbestos Insulator.	Normal Condition.	Without Centr. Cylinder.
2.6	46	56	96	208
5.3	86	104	184	396

FIG. 3.



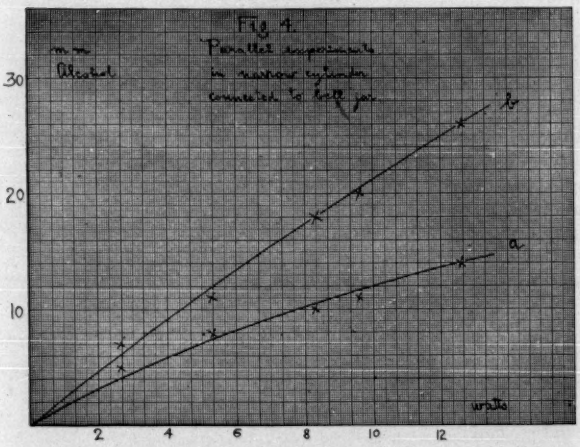
Parallel experiments in bell jar.

measurement was carried out by insulating the vessel *G* by means of a layer of asbestos. There is an increase of pressure to some 20 per cent. A thermal experiment was carried out by omitting the central brass cylinder, causing an increase of pressure by more than 100 per cent.

That the effect in the heating experiment is not essentially higher than that due to the corona, is shown by Fig. 3, in

which two sets are recorded, carried out in a large bell jar instead of the vessel *G*. Whereas the latter had a diameter of 5 cm. and a content of 600 cc., the bell jar had a diameter of 20 cm. and a content of 10 litres. Here curve *a*, referring to the corona, is twice as high as curve *b* referring to the heating experiment. It appears as if the stirring by the electric wind was here favourable to a more effective heating of the whole jar content, whereas in the narrow cylinder it caused the heat conduction by the cylinder walls to be more efficient.

FIG. 4.



Parallel experiments in narrow cylinder connected to bell jar.

Again, another set is shown in Fig. 4, where the narrow cylinder *G* surrounded the device, but the large glass jar was connected to it by means of a three-way stopcock. Here again the heating is more efficient (*b*) than the corona (*a*). It is very remarkable that both effects are dropped to a small fraction of the previous ones. This is understandable from a purely thermal standpoint, since the efficient cooling by the narrow cylinder is added to the deleterious effect of a dead space, trying to cancel the whole effect. The large difference

between the corona curves in Figs. 4 and 3 would be impossible, were a measurable part of the effect due to an ionisation phenomenon.

3. Seeing that the experiments carried out by changing the external conditions of heat conduction are in good agreement with the thermal theory, let us add a brief calculation to show what order of magnitude can be expected for the increase of the number of kinetic elements, which is the basis of the ionisation pressure theory.

For this purpose, the corona will be considered as a space-charge controlled discharge with the boundary condition that the field-strength at the wire is the so-called "starting field-strength," E_s, independently of the applied voltage between wire and plate. Actually there is a small glowing layer around the wire, the corona skin, having a small yet finite thickness, in which ionisation occurs. If the wire is positive, which is the usual arrangement, the electrons are captured by the wire, whereas positive ions are sent out into the surrounding field, establishing there a positive space-charge. The wire is therefore considered as an electrode, emitting positive ions and maintaining at its surface the constant field strength E_s, which is a function of the wire diameter and atmospheric pressure only.

However, the theory entails the knowledge of the whole field distribution, which is somewhat complicated in our arrangement, consisting of eight parallel wires outside a metal cylinder, especially if the semi-conducting glass walls were taken into consideration which, as can be shown experimentally, have a most pronounced influence upon the characteristic of a D.C. corona.

In order to simplify the calculations which only have to reveal the order of the expected effects, the somewhat similar case of a coaxial cylindrical arrangement should be considered, having the same length as our *total* length of wire, the same internal diameter as the diameter of our wire, and the same external radius as our distance between wire and cylinder.

It has to be proved first that the theoretical characteristic of such an arrangement is in satisfactory agreement with our experimental results. For this purpose the current-voltage

characteristic belonging to curve *a*, Fig. 3, should be calculated both experimentally and theoretically. In Table II

TABLE II.
Corona Characteristic.

Volts.	Amps. Observed.	Amps. Calc. from (1).
5.32×10^3	0.47×10^{-3}	0.44×10^{-3}
5.46	0.64	0.72
5.56	0.81	0.92
5.60	1.07	1.00
5.74	1.31	1.28
5.88	1.53	1.56
6.02	1.83	1.84

the first column contains the voltage in volts, the second the current in amps as observed, and the third the current calculated from the empirical formula

$$I = 2.0 \times 10^{-6}(V - 5.1 \times 10^3), \qquad (1)$$

where I = total current in amps., V = applied voltage in volts. Equation (1) represents, therefore, the experimental results. In absolute units

$$I = 1.8 \times 10^6(V - 17.0). \qquad (1a)$$

The theoretical equation [9] for the coaxial arrangement is

$$I = \frac{2lmE_s r_i}{r_e^2}(V - V_s), \qquad (2)$$

where l = length of cylinder, m = mobility of positive ions, r_i and r_e = internal and external radius, and V_s = starting voltage, given by

$$V_s = E_s r_i \log\left(\frac{r_e}{r_i}\right). \qquad (3)$$

Now for our case l = 120 cm., m = 4.10² abs., r_i = 0.0075 cm., r_e = 0.4 cm., E_s = 135 kV/cm. = 450 abs.,[10] conse-

[9] See, for instance, J. J. and G. P. Thomson, "Conduction of Electricity through Gases." Cambridge, 1928 and 1933.

[10] A. v. Engel and M. Steenbeck, "Elektrische Gasentladungen." Berlin Springer, 1934.

quently V_s, from (3), = 13.5 abs., and from (2)

$$I = 2.0 \times 10^6(V - 13.5), \tag{4}$$

which shows a satisfactory agreement in order of magnitude with (1a); actually (4) yields higher values for the current owing to the higher efficiency of coaxial arrangements compared with our experimental device.

As a next step the total space-charge per unit length of the equivalent coaxial arrangement should be calculated. Denoting space-charge density by ρ, current density by i, we have

$$\rho = \frac{i}{2\pi m r E}, \tag{5}$$

where E is the field-strength corresponding to the radius r. On the other hand, the theory yields the relation

$$(rE)^2 - (r_i E_s)^2 = \frac{2i}{m}(r^2 - r_i^2). \tag{6}$$

From (5) and (6), after some re-arrangement,

$$\rho = \frac{1}{2\pi}\sqrt{\frac{i}{2m}}\frac{1}{\sqrt{r^2 + \left(\frac{mE_s^2}{2i} - 1\right)r_i^2}}. \tag{7}$$

From this, the total space-charge per unit length, ρ_l, is given by

$$\rho_l = \sqrt{\frac{i}{2m}}\int_{r_i}^{r_e}\frac{r\,dr}{\sqrt{r^2 + \left(\frac{mE_s^2}{2i} - 1\right)r_i^2}}. \tag{8}$$

Integrating and considering that $\frac{mE_s^2}{2i} \gg 1$, we obtain

$$\rho_l = \sqrt{\frac{i}{2m}}\left(\sqrt{r_e^2 + \frac{mE_s^2}{2i}r_i^2} - \sqrt{\frac{m}{2i}}E_s r_i\right). \tag{9}$$

The data for equation (9) were already given. As to i, let us choose the fourth figure in Table II ($I = 1.07 \times 10^{-3}$ amps.), corresponding to 6 watts and a pressure of 122 mm. alcohol in

Fig. 3. This means that $i = 2.7 \times 10^4$ abs. With these values

$$\rho_i = 1.16 \text{ abs.}$$

Asking for the numbers of carriers corresponding to this space-charge, we divide by e (assuming monovalent ions) and obtain 2.5×10^9 ions/cm. This figure represents an upper value for the increase of kinetic elements. If ionisation (for nitrogen) takes place according to

$$N_2 \rightarrow N_2^+ + e^-,$$

then the increase of the total number is nought, since the electrons are directly captured by the wire. If, on the other hand, the process

$$N_2 \rightarrow N + N^+ + e^-$$

occurs, leading to atomic ions, instead of molecular ones, then each positive ion means an addition to the total number. Evidently the total increase lies between zero and 2.5×10^9 per unit length.

In fact, molecular ionisation is generally the prevailing one, as is shown for instance by measurements on the ionisation of hydrogen by beams of electrons [11] with maximally 8 per cent. atomic ions, corresponding to 200 volt-electrons ionising energy.

Assuming, however, the upper limit to be valid and considering that the volume of our unit cylinder is 0.5 cc., containing 1.3×10^{19} molecules, we get a relative increase of

$$2 \times 10^{-10}.$$

Also one has to consider that any additional space in the device, as is certainly present in our arrangement, tends to decrease this upper value still further. In comparing the above figure with the experimental relative increase of pressure of 10^{-2}, one might conclude that the effect considered is at least seven orders too low and has nothing to do with the observed one, even if allowance is made for some uncertainty due to our simplified model.

Another mechanism, namely the local increase of pressure due to space-charge formation has been considered by *Tyndall*

[11] H. D. Smyth, *Rev. Mod. Phys.*, 3, 347, 1931.

and shown to be much lower than the observed effect. Apart from that consideration, this possibility is specially discarded by our device (Fig. 1) in which the pressure was measured at a point at finite distance from the actual discharge space, whereas the effect just mentioned is mainly localised at the plate facing the wires, considerably decreasing with increasing distance from the electrode.

SUMMARY.

The thermal theory of the increase of pressure due to corona in a closed space is strengthened by special experiments carried out in varying the conditions of heat conduction.

Also it is shown by calculation that the increase of the number of kinetic elements, as considered by the ionisation theory, is several orders too low in order to explain the observed effect, whereas the so-called space-charge pressure is discarded by the experimental arrangement itself.

The author is much indebted to Messrs. Metropolitan-Vickers Electrical Co. Ltd., Manchester, England, for a grant enabling this work to be carried out.

Technological Trends and National Policy.—The National Resources Committee have recently published a rather voluminous report prepared by the subcommittee on Technology with the assistance of various universities, laboratories, and governmental bureaus. It presents a survey of most of the great fields of technology and applied science with an object of showing the kinds of new inventions which may affect living and working conditions in America in the next 10 to 25 years. Among the findings listed in the report, it is stated that there are many new inventions that will have important influences upon society and hence upon all planning problems. The report brings out that while the influence of invention may be so great as to be immeasurable, there is usually opportunity to anticipate its impact upon society since it never comes instantaneously without signals. There are faint beginnings, development, diffusion, and social influences, occurring in sequence, all of which require time. From the early origins of an invention to its social effects the time interval averages about 30 years. The report recommends in part, that a series of studies be undertaken by planning agencies or boards on the following inventions: the mechanical cotton picker, air conditioning equipment, plastics, the photo-electric cell, artificial cotton and woolen-like fibres made from cellulose, synthetic rubber, prefabricated houses, television, facsimile transmission, the automobile trailer, gasoline produced from coal, steep-flight aircraft planes, and tray agriculture. The most important general conclusion arrived at is the continuing growth of the already high and rapidly developing technology in the social structure of the nation and hence the hazard of any planning that does not take this fact into consideration.

R. H. O.

DEVICES FOR THE PHOTOELECTRIC CONTROL OF EXPOSURE IN PHOTOGRAPHIC PRINTING.*

CLIFTON TUTTLE.

In a recently published paper,[1] the author discussed the possibility of applying photometry—especially photoelectric photometry—to the printing of amateur negatives. It appears from the data there presented that, statistically, a high percentage of satisfactory results could be obtained by using a measurement of the total density of a picture negative as a criterion of the amount of light which should be used in making the print. A simple inverse proportionality exists between the total light transmittance of the typical pictorial negative and the required printing exposure—this latter value being defined as the product of time and intensity incident upon the negative during printing. If the total negative transmittance is denoted by T_N or the logarithm of its reciprocal by D_N and the required printing exposure is denoted by E_p, the desired relationship may be written:

$$E_p = \frac{K}{T_N}$$

or

$$\log E_p = D_N + \log K.$$

It is the purpose of this paper to discuss some of the possible methods and devices by means of which the signal which results from illumination of a photocell by light transmitted through a negative may be used to control the printing exposure automatically. The stated relationship may be regarded as the calibration function for devices designed to do this job.

Since the value of required printing exposure (E_p) is the product of two factors, time and intensity, it is apparent that there are two ways in which the photoelectric signal generated by the negative-transmitted light may be applied to automatic

* Communication No. 633 from the Kodak Research Laboratories.

printing control. The time of printing may be kept constant while the intensity is varied, or the intensity may be kept constant while the time is varied. This fact coupled with the fact that exposure may be controlled in some cases, namely, in optical or projection printers, either at the source or between the negative and positive, leads to many variations in possible automatic printing mechanisms; so many indeed, that it is hardly practical to make anything like a complete survey of the possibilities. It will be more to the point to deal in detail with a few of the ideas which seem especially well adapted to fit into the present conditions of the photofinishing industry.

General specifications for a successful automatic printer may be set forth under the headings of ruggedness, versatility, speed, accuracy, and cost.

Ruggedness. The personnel of photofinishing establishments is, in general, unacquainted with the intricacies of electronic tube circuits. The photoelectric control to be acceptable to the trade must, therefore, be designed in such a manner that servicing is confined to simple mechanical adjustments throughout the life of the apparatus. It is probable that a single printer might be expected to make a million prints per year and to have a life of several years.

Versatility. The available exposure range of the printer must be sufficient to take care of the extremes of negative density which the photofinisher at present considers "printable." This means that, at maximum, the device should be able to give twenty or thirty times its minimum value. Probably also, it should be possible to shift the entire exposure range so that several positive materials of the same general type but of different sensitivities could be used. This requirement would be satisfied by a factor of five. To sum up the matter of exposure range in relative terms: if 100 exposure units are available to print the densest negative on the slowest paper, the printer at the setting for this paper should provide for a thin negative printing of five units or less. For the fastest paper of the same type, it should be possible with a level-shifting device, to set the levels at 20 exposure units for the densest negative and one exposure unit for the thinnest.

Speed. With present equipment, the output of a good operator is something in excess of 300 contact prints per hour.

Automatic equipment with an inexperienced operator should equal or better this speed. Since there is an unavoidable time loss in masking negatives and handling the printing material, it is obvious that the actual exposure time must be kept at a minimum. It is reasonable to assume that the exposure time of an automatic printer should not exceed that of most modern manually operated printers, an average value for which is about one second. An approximation to the value of maximum required intensity can be made upon the basis of the allowable exposure time. To print a dense negative upon a comparatively insensitive contact printing paper, an exposure of the order of 100,000 meter candle seconds is needed—100,000 meter candles at one second.

Accuracy. Probably greater accuracy should be maintained in the photoelectric control than would seem requisite from a cursory inspection of the data of the previously cited paper. Although it is shown that for the average negative there is a tolerance of nearly 20 per cent. in both directions, the printer designed to expose all negatives upon the basis of a total transmission measurement should adhere closely to the statistically determined calibration. Throughout that portion of the exposure range where the frequency of occurrence is highest, the instrumental error should be not greater than five per cent. At the extremes of the range, the permissible error may be somewhat greater without serious detriment to the statistical results because of the lower number of very thin and very dense negatives which will be encountered.

FIXED TIME WITH CONTROLLED INTENSITY SYSTEMS.

The first group of automatic printing devices which will be discussed are those in which the exposure time is constant and the intensity is photoelectrically controlled. This method has one inherent advantage over the other alternative. With all photographic materials there is some failure of the Bunsen-Roscoe reciprocity law, which failure results in differences of photographic effect at different intensity levels when the time-intensity product is kept constant. The amount of failure is not the same for different materials. If, then, an automatic control in which the intensity incident upon the sensitive paper is not constant is compensated for to take account of the

reciprocity failure with one kind of material, there is no assurance that the same compensation will be obtained for other positive materials which might be used.

A second factor, possibly worth some consideration, is that a controlled intensity method is easily applied in two steps: 1. The measurement of negative transmission and presetting of the printing intensity level on the basis of the measurement. 2. The actual printing for a constant time at the predetermined intensity level. Thus, in a contact printer, the negative transmission may be measured before the positive material is applied. The variable-time method on the other hand works best if the transmission measurement and the printing take place simultaneously. In a contact printer, this means that the transmission measurement is made through both negative and paper and its accuracy is subject to the different absorptions of different pieces of paper stock.

There are several ways in which either the intensity incident on the negative (in a contact printer) or the intensity incident on the paper (in a projection printer) may be controlled:

1. The actinic output of the source itself may be controlled, as, for instance, by varying the voltage applied to a tungsten lamp.

2. Light from the source may be absorbed before it reaches the negative (contact printing) or between the negative and paper (projection printing).

3. The distance of the lamp from the negative may be varied.

Practical considerations appear to narrow the choice, at least for the contact printer. Uniform and intense illumination of a field as large as the largest amateur negative must be provided. A 500-watt tungsten lamp set about eight inches from the negative plane will satisfy these requirements but sources of lower actinic output will not be sufficient. Inverse square law variation over the intensity range of 20 to 1 is obviously too clumsy to consider and the insertion of any kind of light-absorbing device between the lamp and negative is beset with difficulties. The simplest absorbing device would be an optical wedge. This wedge would have to be heat-resistant and free from imperfections which might cast

shadows on the negative. If, instead of a wedge, a lens system with a diaphragm is considered, it is found that, to obtain the requisite intensity, the aperture must be great and difficulty with nonuniformity is encountered. Aside from other considerations, either of the latter systems is expensive.

In a projection printer, absorption of light can take place at the objective. Either a wedge or a diaphragm could conceivably be used, though, of the two, the wedge is much to be preferred, as will be shown later.

The most practical opportunities for the application of a photoelectric signal to the control of intensity appear then to be either to control the source itself or to control the light after it has passed the negative. The first method is applicable either in contact or projection printing, the second in projection printing only. Devices which have been proposed for these two methods will now be discussed.

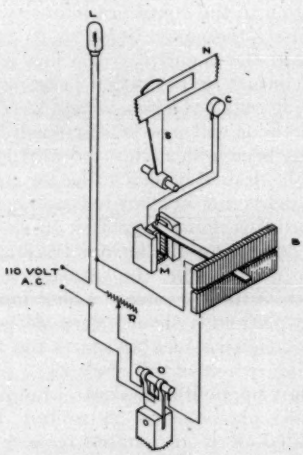
As has already been indicated, a 500-watt lamp comes near to having all of the desired qualifications for a printing source. It is capable of delivering at its rated wattage sufficient uniform light for printing dense negatives on slow paper in one second and by decreasing the terminal voltage to about 50 per cent. of the rated value, the printing intensity can be reduced to 1/30th of its top value. Lamp input to print the negative density extremes should vary perhaps 350 watts. The photoelectric signal which measures the transmission of the same negative extremes will vary by a few microwatts. It is of course not impossible to control lamp input directly from an amplified photoelectric signal but, because of the large gain required, it is reasonable to seek to avoid this procedure.

A photoelectric measuring system which accomplishes the control of a large wattage without any conventional amplifier has been described in the patent literature.[2] This device uses the output from a photocell to insert resistance into the circuit of the printing lamp. The mechanical operation of this photoelectric rheostat is indicated schematically in Fig. 1.

Light for measuring the negative, N, is supplied by the lamp, L, the initial intensity of which has been adjusted by the rheostat, R. Between the light source and negative is a shutter, S, which is a nonactinic light-transmitting filter.

The cell, *C*, measures the negative transparency and a pointer on the microammeter, *M*, is deflected in accordance with the cell signal. A small iridium rod is carried by the movement pointer and this swings in a space between two rheostat elements, *B*. After the pointer attains the proper deflection, these two elements bite together, forcing the iridium rod into contact with both of them. This action sets the resistance of an as yet inactive circuit.

FIG. 1.



Automatic lamp resistance control.

A piece of sensitized photographic paper is now placed in contact with the negative and, though the cell current is thereby reduced, the microammeter does not change its deflection because it is held firmly by the clamped resistance jaws.

A constant timing mechanism now operates to move the shutter aside for a short exposure period and simultaneously the switch, *D* (Fig. 1), operates to replace the measuring resistance, *R*, by the photoelectrically assigned resistance.

The lamp intensity is thus brought to the proper level for printing the measured negative.

It is interesting to follow the steps leading to the design of the electrical circuit of this printing control.

As resistance is inserted in series with a tungsten lamp, the logarithm of the photographically measured intensity varies linearly with the resistance throughout a large intensity range. For the series resistance-intensity relationship may be written the equation:

$$R_s + M \log I = K.$$

From a consideration of the general automatic printer calibration previously stated, it follows that the equation

$$R_s + L \log D_N = K$$

defines the manner in which it is desired to vary the series resistance with the total negative density. Hence, the relation between the photoelectric signal $C_{p.e.}$ and the resistance which should be introduced as a consequence of this signal is:

$$\log C_{p.e.} = KR_s,$$

if it is assumed that the response of the photocell is directly proportional to the illumination.

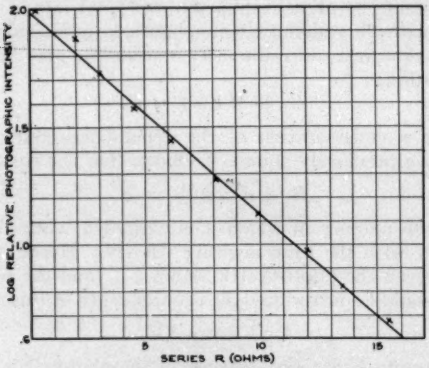
In the apparatus being discussed, two ways of accomplishing this sort of result are apparent. One is to warp the deflection scale of the microammeter so that geometric increments of photoelectric current will produce arithmetic increments of deflection. This may be done by making the air gap of the magnetic circuit of the meter increase with deflection. A second way is to wind the rheostat on a core of which the cross section increases logarithmically from end to end. Either method introduces some manufacturing difficulties.

A third method which is much simpler from the manufacturing point of view makes use of a fortunate property of parallel resistances. If a fixed resistance is shunted with the resistance which varies linearly with photoelectric signal, an approximation to the desired relationship may be obtained over a limited range.

A numerical example from experimentally determined data is of interest to illustrate the effectiveness of such a control system. The photographic intensity of a 500-watt, 100-volt

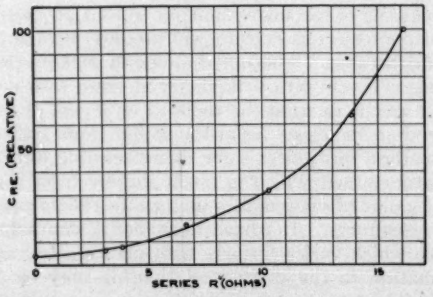
projection-type tungsten lamp was measured for different values of resistance in series with it and a 110-volt line. The result is shown graphically in Fig. 2.

FIG. 2.



Relation between series resistance and photographic intensity of a 500-watt, 100-volt lamp on a 110-volt line.

FIG. 3.



Relationship between photoelectric measuring current and series resistance.

In Fig. 3, the desired relationship between photocell current and series resistance is shown by the curve. This

curve was computed on the assumption that the photocell current is linearly related to the total transmission of the measured negative. A range of 25 to 1.0 establishes the limits of this curve, a range corresponding to a negative density variation of 1.4, for instance, from a thin negative of 0.4 to a dense negative of 1.8.

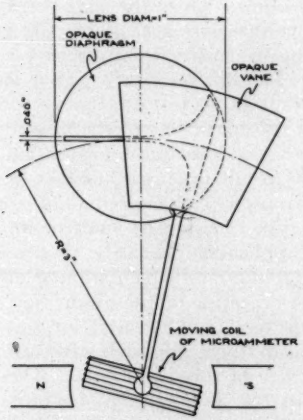
A parallel circuit combination of variable and fixed resistances may be found which closely approximates the desired relationship. The points represented by circles on the graph are determined for a combination in which the fixed resistance is 22 ohms and the variable rheostat controlled by meter deflection is 60 ohms. Over the high-resistance portion of this curve, the compensation is practically perfect. Hence, negatives varying in density from 0.4 to 1.4 would be accurately printed. The low-resistance region (corresponding to negative densities from 1.4 to 1.8) is not so perfectly fitted but here, because of the sparseness of the negative population in the high-density region, it is quite certain that the error would have a negligible result upon the number of passable prints obtained from a representative group of amateur negatives.

The second type of intensity control which will be considered is one applicable primarily to projection printing. Devices adapted to automatic regulation of either the aperture of the projection objective or the absorption of light passing through the objective may be used for this purpose. The simplest mechanism to provide such a control would be of the nature of the device pictured in Fig. 4. This is essentially a microammeter to the moving coil of which is attached an opaque vane at the end of a pointer. The vane swings between the components of the projection objective and so limits its aperture. Such a movement could be actuated directly by the output of a photocell measuring total negative transmission. Conceivably, the movement of the vane might be made to disclose areas of a fixed diaphragm which would be inversely proportional to the negative transmission.

This sort of control has proved successful in the automatic administration of second exposure in the processing of 16-mm. reversal film,[3] but its adaptation to negative-positive printing does not look promising.

If it is assumed as before that photoelectric current and meter deflection are linearly proportional to total negative transmission, the desired inverse proportionality between disclosed diaphragm area and meter movement is impossible to achieve without introducing serious mechanical difficulties in the construction of the shaped diaphragm and even more serious optical difficulties in the use of an objective limited by the resultant shape. Both mechanical and optical difficulties become more severe, the greater the exposure range to be

FIG. 4.



Direct microammeter control of lens aperture.

covered. The dimensioned diagrammatic sketch of Fig. 4 gives a fair idea of the unusable shape which results when a diaphragm is computed to operate over the limited range of 16 to 1. The dimensions (lens diameter and meter pointer length) assumed for this construction are reasonable for practical purposes. The mechanical difficulty is to obtain sufficient accuracy in shaping the small end of the diaphragm. The optical difficulties are threefold: 1. The limited aperture is inefficient. 2. Diffraction effects at the lower end spoil the

image. 3. Uniformity of image illumination is impaired as the vane swings from one end to the other.

Substitution of an absorbing wedge to act over the entire objective removes most of the optical objections but introduces new mechanical difficulties. A wedge of sufficient transmission range would be much larger and heavier than the vane suggested in the preceding paragraphs. Its inertia would be so great that there would be little hope of making a rapid adjustment directly from the output of a photoelectric cell. Then, too, the making of a wedge of even fairly small dimensions and of an accurately regulated gradient is no small problem. Both difficulties appear to be overcome by the

FIG. 5.

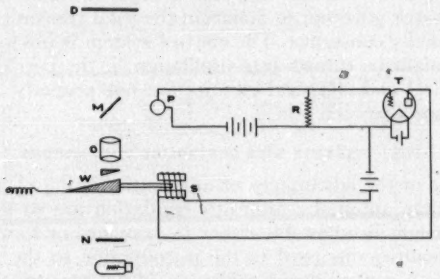


Diagram of constant signal amplifier.

method disclosed in two recent patents.[4] With the device described, ample power to move a body of the requisite wedge mass is provided and the difficulty of regulating the wedge gradient is eliminated.

The schematic diagram of Fig. 5 illustrates the manner of operation of this intensity-controlling device. The photocell, *P*, is illuminated by a part of the light transmitted by the negative, *N*, the wedge, *W*, and the objective, *O*. The semi-transparent mirror, *M*, diverts this illumination to the cell while letting the major portion through to form an image on the positive material at *D*. The cell is polarized by a battery in series with a coupling resistor, *R*, and so connected to the input circuit of the tube, *T*, that variations in the potential

drop across the resistance, R, are sufficient to vary the potential of the tube through its critical range. The constants of the circuit are so chosen that a negligibly small variation in photocell current will produce a very large variation in the plate current of the tube. This plate current is used through the medium of a solenoid, S, to control the position of the wedge. The solenoid might obviously be replaced by a moving-coil galvanometer whose pointer carries the wedge.

It is interesting to note that, with this circuit, it is not necessary to fit the response characteristics of the photocell and the moving element, and the gradient of the wedge to fulfill the automatic printer calibration relation. This device, which operates in a manner analogous to the automatic volume-control circuits of radio reception, functions as a photoelectric governor to maintain the total transmitted light substantially constant. The control system is obviously one which might be thrown into oscillation, if the periods of the mechanical and electrical circuits are not properly adjusted with respect to each other.

V. 19

FIXED INTENSITY WITH CONTROLLED TIME SYSTEMS.

Some of the advantages of automatic timing of a printer rather than automatic intensity regulation are so appealing that it might be allowable either to disregard or to avoid the two difficulties discussed in the introduction to the previous section. A control device which could use any type of light source delivering to a negative any intensity, either constant or variable, and which could collect total transmitted light until the requisite total energy has been received, appears to be an elegant solution to the automatic printing problem.

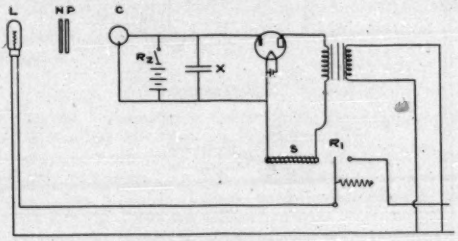
Most obvious among the possible measuring devices for a time-intensity integral is the combination of a photoelectric cell and a condenser. A number of patents [5] show such a combination applied to an automatic printer. The circuit of Fig. 6 is similar to that disclosed in the first of these specifications.

A source of light, L, is connected to the power line through the switch, R_1. Light passes through the negative and positive, N and P, and a photocell, C, is placed so as to receive a definite portion of the total transmitted light. The cell is

polarized by a battery shunted with a condenser, X, which must be of high resistance and high capacity. When the switch, R_2, is opened, the only path through which the condenser can discharge is the photocell. Since conductance of the photocell is proportional to the intensity transmitted by the negative and positive, the time of the condenser discharge is inversely proportional to the intensity which exposes the positive. It has been suggested that by providing a high resistance leak across the condenser, it is possible to vary the response from strictly inverse proportionality in a manner to compensate for reciprocity failure.

The grid and cathode of a three-electrode tube are shunted with the condenser. As the condenser discharges, the po-

FIG. 6.



Circuit of condenser discharging timer.

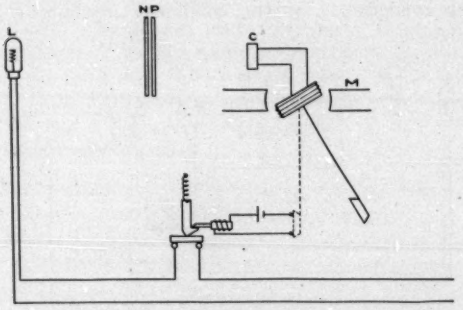
tential of the grid gradually rises until the plate current becomes sufficient to enable the solenoid, S, to attract the switch, R_1, thereby opening the lamp circuit and terminating the exposure. This same scheme with some modifications becomes applicable to projection printing.

Another patent [6] suggests a different method of time control based upon the speed of response of a damped D'Arsonval galvanometer actuated by a pkotoelectric current. If the restoring torque of the movement is small in comparison to the magnetic force, and if the magnetic damping is large in comparison to the frictional damping, the period of the coil movement is approximately inverse to the strength of the coil current and hence to the intensity striking the cell which

furnishes the current. The circuit proposed by the inventor to apply this principle to automatic printing is shown in Fig. 7.

A light source, *L*, illuminates the negative and positive, *N* and *P*, which are shown in contact. A photocell, *C*, measures the transmitted intensity. Its output is connected to the coil of a galvanometer relay, *M*. The coil swings with a speed proportional to the intensity until the pointer makes the contact of a secondary circuit which operates a tripping device that terminates the exposure. A mechanical linkage from the

FIG. 7.



Device in which speed of meter movement is directly proportional to photoelectric signal.

negative-positive platen movement can be provided to reset the galvanometer coil and to close the lamp circuit switch.

CONCLUSION.

The devices described in this account by no means include all of the patented ideas for the automatic control of exposure. A number of additional suggestions of interest are briefly abstracted in the references included at the end of the paper. It is quite obvious, also, that control circuits of the nature of those which have been applied in photoelectric recording photometers might be drafted into the automatic printing field. The circuit of Hardy's [7] photoelectric colorimeter, for example, performs the very operation required of an automatic

printing control. It automatically controls the intensity of the light transmitted by the sample to match the intensity transmitted by an invariable optical system. A mechanism described by the author [8] for a recording densitometer might also be adapted to automatic printing.

It is true, however, that most of the photoelectric photometer designs have sacrificed simplicity for accuracy—a degree of accuracy which must compete with visual photometry. The printer control does not need to approach this refinement, but it must successfully meet other requirements of low cost, ruggedness for use by unskilled operators, and high speed of operation. These last were the considerations which were borne in mind in the choice of the devices which have been described.

The author's indebtedness to Mr. R. N. Carter of the Eastman Kodak Company for his help in searching the patent literature of this subject is gratefully acknowledged.

March, 1937.

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2. U. S. Patents Nos. 1,976,310 (Clifton Tuttle) and 1,987,036 (Clifton Tuttle and D'Arcy A. Young).
3. U. S. Patents Nos. 1,742,943 (Clifton Tuttle and Herbert E. White) and 1,908,610 (Loyd A. Jones and Clifton Tuttle).
4. U. S. Patents Nos. 1,973,470 (Armand M. Denis) and 1,973,469 (Armand M. Denis).
5. U. S. Patents Nos. 1,973,468 (Armand M. Denis), No. 1,939,243 (Frank Twyman), Br. Patent 344,900 (Cambridge Instrument Company), and U. S. Patent 2,000,589 (Albert B. Fuller).
6. U. S. Patent No. 1,966,303 (John W. McFarlane).
7. HARDY, ARTHUR C., "Recording Photoelectric Color Analyzer," *J. Optical Soc. Amer.*, **18**, 96 (1929).
8. TUTTLE, CLIFTON, "A Recording Physical Densitometer," *J. Optical Soc. Amer.*, **26**, 382 (1936).

SUPPLEMENTARY LIST AND DESCRIPTION OF PATENTS DEALING WITH EXPOSURE CONTROL MECHANISMS.

U. S. 700,083, Poliakoff. Suggests a device wherein light is reflected onto a selenium cell by a light-sensitive reflector which darkens under exposure. After darkening has proceeded to a predetermined extent, the cell current is reduced to the point where it is too feeble to hold open a shutter. At this point, the shutter drops and terminates the exposure.

Ger. 299,278, Dix. Suggests a selenium cell in circuit with a magnetic trip which operates a shutter. Supposedly the brighter the light, the quicker will the cell close the circuit.

Ger. 377,251, Traut. Shows a solenoid-operated dashpot. The solenoid is in circuit with the printing light with the result that the speed of the dashpot piston moving to stop the exposure depends upon the energization of the printing lamp. (Not photoelectric but might be made so.)

U. S. 1,912,740 and 1,954,338, Tuttle, McFarlane, and White. Uses a continuously rotating optical density wedge which varies the intensity falling onto the photocell through the negative and paper. A critical current relay in circuit with the photocell operates to terminate the exposure.

Br. 339,781, Westinghouse Lamp Company. Discloses a device to regulate X-ray dosage so as to maintain its constancy. The control is effected by means of an element whose resistance varies in accordance with received radiation, thereby regulating the charging rate of a condenser.

U. S. 1,946,621, Hopkins. Shows an arm which moves at uniform velocity until it encounters a microammeter needle at which point the exposure is terminated. The microammeter which fixes the path length is actuated by current from a photoelectric cell which measures the negative-transmitted light.

U. S. 1,946,612, Carter. Combines the variable pointer velocity idea of McFarlane[8] with that of Hopkins.

U. S. 1,947,490, Gwozdz. Suggests the idea of allowing the measuring photosensitive element to control the field of a generator which supplies the light source. Several other ideas which are difficult to describe, without diagrams, are disclosed in this patent.

U. S. 1,312,289, Wenderhold. Shows a continuous motion picture printer in which light transmitted by the negative acts through a photocell to adjust a shutter, thereby controlling the length of time for which the negative is printed.

Ger. 392,218, Koch, and U. S. 1,813,635, Meyers and Wilkinson. Suggest a moving vane method of adjusting the aperture of a lens system (see reference 3).

U. S. 1,836,607, Malcolm, and Fr. 673,698, Soc. Indépendente de Télégraphie Sans Fil. Both suggest methods of using the photoelectric signal to vary the resistance of a printing lamp circuit.

Austrian 83,912, Maurich. Discloses a mechanism in which a selenium cell adjusts a lens diaphragm opened by means of a spring-biased solenoid.

Ger. 313,770, Machts. Allows a photocell to feed current through an oxy-hydrogen generator. A resistance heating element within the gas chamber is connected in circuit at the same time as the gas generation starts. When the temperature of the heating element reaches a certain value, the gas detonates with consequent increase in volume. As a result, a piston in the chamber is pushed out. The amount of volume increase, and hence of the piston movement, is proportional to the amount of gas generated. The movement is used to time the exposure.

U. S. 2,058,562, Bucky and Einstein. Suggests the control of an optical density wedge over a lens by means of photocell output.

U. S. 2,058,483, Mihalyi, and U. S. 2,058,531, Tuttle. Both disclose a diaphragm control arrangement which utilizes the cell-controlled pointer of a microammeter as a mechanical stop for limiting the adjustment of the diaphragm.

U. S. 2,051,061, Tönnies; U. S. 1,759,630, Renaldy; Fr. 681,692, Raab; U. S. 1,934,484, Cammilli. Show means for using cells which operate diaphragm controls.

U. S. 2,032,633, Riszdorfer. Discloses a diaphragm consisting of two elements each of which is carried by a D'Arsonval coil energized by the photocell.

U. S. 1,925,547, C. Tuttle and F. Tuttle. Proposes utilizing the photoelectric signal to set the position of a condenser rotor which tunes or detunes a high-frequency circuit, thus altering the power picked up from an oscillator. This power feeds the printing lamp.

U. S. 2,038,430, Jameson. Discloses a moving mirror actuated by a photoelectric cell. (Similar to the McFarlane idea.[6])

Ger. 626,052, Szuboritis. Proposes scanning the negative and using the response of a photocell which reads the highest density to control printing exposure.

U. S. 1,929,105, Sperbeck. Discloses a device in which a lamp is increased in intensity until the negative-transmitted light activates a photocell to a critical value, whereupon the cell opens a switch which stops a revolving contact at a point which will include enough lamps to print properly.

U. S. 2,024,661, Riszdorfer. Varies the intensity passing through a lens uniformly and uses the photoelectric signal to trip a shutter at a critical value.

Resin-Bonded Plywood for Construction.—(*Chemical and Metallurgical Engineering*, Vol. 44, No. 9.) Wood has been familiar and universally used as a material of construction for so long that it is often thought of in terms of its weaknesses. A basic disadvantage, that of low strength across the grain, is overcome by the manufacture of plywood, where each successive layer of sawn lumber or wood veneer runs at right angles to both adjacent layers. The plywood construction introduces a new material next to each successive layer of wood, namely, an adhesive, and if this is not as chemically resistant as the wood itself, a new weakness is introduced in attempting to overcome the older ones. In the past few years, a synthetic resin, binder in the form of Tego resin film has been adopted by a number of manufacturers. By applying it with wholly new operating equipment and technique, they have succeeded in establishing Tego-bonded plywood as a well recognized product. This plywood is made with the dry resin film interleaved between the layers of wood, which sets in a hot press to give a permanently cured joint between the layers of wood. The chemical resistance of this new type of plywood is really limited only by the properties of the wood employed, or by the protective coatings used on it. The principle features of the bond in plywood are its complete insolubility in cold or boiling water for an indefinite period of time, and its repellance of any mold growth on damp locations, which ordinarily hastens delamination and destruction of plywood. The resin itself is in an irreversible, cured condition, and among the commoner chemicals, is attacked only by strong alkali

R. H. O.

A TABLE OF CATENARY ELEMENTS.

BY

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In the year 1924, while engaged in computations relating to the design and construction of the Bear Mountain Hudson River Bridge, the writer accidentally came into possession of a photographic copy of pages 328 and 329 of Nystrom's "Pocket Book of Mechanics and Engineering," first published in 1854, and published in its 21st and final edition in 1895. A fire in the latter year destroyed the plates and text, so that the book is now out of print and probably but few copies are in existence.

The two pages in question are entitled "The Catenary." They contain a number of trigonometric equations, all in terms of natural functions, which, although not so described, are found upon investigation to relate to what may be called a "unit catenary," that is, a catenary whose parameter is unity. There is also given a "Table for the Catenary Curve," computed for angles v between the curve and the vertical at the ends of the catenary from 30° to 89°, varying by single degrees or even more, and containing values of x_1, y_1 and l_1 (see Fig. 1) together with ratios of the latter quantities.

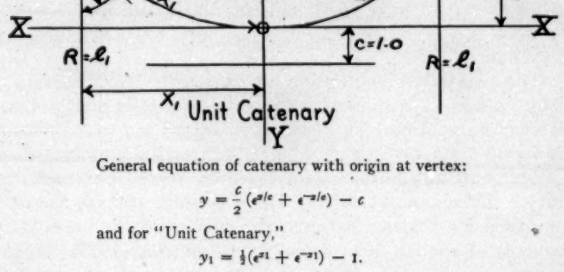
The table is too fragmentary to be of any value for computations which require anything but a rough approximation and the trigonometric expressions are very complicated and are susceptible of much simplification.

The writer, however, saw in the matter presented the possibility of a novel method of handling the catenary, by using natural instead of hyperbolic functions. He developed the three simple equations (1), (2) and (3) for x_1, y_1 and l_1 given in the following description, and, by a tentative process, performed with great accuracy the catenary computations for the Bear Mountain Bridge, having a central span of 1632 feet.

Seeing the advantages of this method of procedure, the writer has since computed the following table of quantities x_1, y_1 and l_1 together with ratios x/l, y/l and y/x for every ten minutes of angle v from 44° to 90°, comprising a much greater range than is ever likely to be encountered in suspension bridge practice.

The quantities x_1, y_1 and l_1 are respectively the semi-span, the centre sag and the semi-length of curve for a catenary having a weight of unity per unit of length of curve and a parameter of unity. This is called a "unit catenary."

FIG. 1.



General equation of catenary with origin at vertex:

$$y = \frac{c}{2}(e^{x/c} + e^{-x/c}) - c$$

and for "Unit Catenary,"

$$y_1 = \tfrac{1}{2}(e^{x_1} + e^{-x_1}) - 1.$$

For any other catenary with a weight of unity per unit of length of curve, and a parameter c, the values of x, y and l for the same angle v will be respectively equal to cx_1, cy_1 and cl_1.

If any two of the elements x, y and l of a catenary are known, their ratio is first found and by linear interpolation in the column containing the corresponding ratio, and also in other columns of the table, values of v, x_1, y_1 and l_1 may be found. The value of c is then obtained from any one of the relations

$$c = \frac{x}{x_1}, \quad c = \frac{y}{y_1} \quad \text{or} \quad c = \frac{l}{l_1}.$$

φ	x_1	y_1	l_1	$\frac{x}{l}$	$\frac{y}{l}$	$\frac{y}{x}$
44°	0.906275	0.439557	1.035530	0.875180	0.424474	0.485014
44° 10′	0.902094	0.435239	1.029520	0.876228	0.422759	0.482477
44° 20′	0.897926	0.430960	1.023546	0.877269	0.421046	0.479951
44° 30′	0.893769	0.426718	1.017607	0.878305	0.419335	0.477436
44° 40′	0.889625	0.422513	1.011704	0.879334	0.417626	0.474934
44° 50′	0.885493	0.418345	1.005835	0.880357	0.415919	0.472443
45°	0.881374	0.414214	1.000000	0.881373	0.414214	0.469964
45° 10′	0.877266	0.410118	0.994199	0.882384	0.412511	0.467496
45° 20′	0.873170	0.406057	0.988432	0.883389	0.410810	0.465038
45° 30′	0.869086	0.402032	0.982697	0.884388	0.409111	0.462592
45° 40′	0.865013	0.398042	0.976996	0.885381	0.407414	0.460157
45° 50′	0.860952	0.394086	0.971326	0.886368	0.405719	0.457732
46°	0.856903	0.390164	0.965689	0.887349	0.404026	0.455318
46° 10′	0.852865	0.386275	0.960083	0.888324	0.402335	0.452915
46° 20′	0.848838	0.382420	0.954508	0.889293	0.400647	0.450523
46° 30′	0.844822	0.378598	0.948965	0.890256	0.398959	0.448140
46° 40′	0.840817	0.374809	0.943451	0.891214	0.397274	0.445768
46° 50′	0.836824	0.371052	0.937968	0.892166	0.395591	0.443405
47°	0.832841	0.367327	0.932515	0.893112	0.393910	0.441054
47° 10′	0.828869	0.363634	0.927091	0.894053	0.392231	0.438712
47° 20′	0.824907	0.359972	0.921697	0.894988	0.390554	0.436379
47° 30′	0.820956	0.356342	0.916331	0.895917	0.388879	0.434057
47° 40′	0.817016	0.352742	0.910994	0.896841	0.387205	0.431744
47° 50′	0.813086	0.349172	0.905685	0.897759	0.385534	0.429440
48°	0.809167	0.345633	0.900404	0.898671	0.383864	0.427146
48° 10′	0.805258	0.342123	0.895151	0.899578	0.382196	0.424862
48° 20′	0.801359	0.338643	0.889924	0.900480	0.380531	0.422586
48° 30′	0.797470	0.335193	0.884725	0.901376	0.378867	0.420320
48° 40′	0.793591	0.331771	0.879553	0.902267	0.377204	0.418062
48° 50′	0.789722	0.328377	0.874407	0.903152	0.375543	0.415814
49°	0.785863	0.325013	0.869287	0.904032	0.373884	0.413574
49° 10′	0.782014	0.321677	0.864193	0.904907	0.372227	0.411344
49° 20′	0.778174	0.318368	0.859124	0.905776	0.370572	0.409122
49° 30′	0.774344	0.315087	0.854081	0.906640	0.368919	0.406909
49° 40′	0.770523	0.311834	0.849062	0.907499	0.367268	0.404704
49° 50′	0.766712	0.308607	0.844069	0.908352	0.365618	0.402507
50°	0.762910	0.305407	0.839100	0.909200	0.363970	0.400319
50° 10′	0.759117	0.302234	0.834155	0.910043	0.362324	0.398139
50° 20′	0.755334	0.299087	0.829234	0.910881	0.360679	0.395967
50° 30′	0.751559	0.295967	0.824336	0.911714	0.359036	0.393803
50° 40′	0.747794	0.292872	0.819462	0.912542	0.357395	0.391648
50° 50′	0.744038	0.289803	0.814612	0.913365	0.355756	0.389501
51°	0.740290	0.286760	0.809784	0.914182	0.354119	0.387362
51° 10′	0.736552	0.283741	0.804979	0.914995	0.352483	0.385230
51° 20′	0.732822	0.280748	0.800196	0.915803	0.350848	0.383105
51° 30′	0.729101	0.277779	0.795436	0.916606	0.349216	0.380988
51° 40′	0.725388	0.274834	0.790697	0.917403	0.347585	0.378879
51° 50′	0.721683	0.271914	0.785981	0.918194	0.345955	0.376778

v	x_1	y_1	h	$\frac{x}{l}$	$\frac{y}{l}$	$\frac{y}{x}$
52°	0.717988	0.269018	0.781286	0.918982	0.344327	0.374683
52° 10′	0.714301	0.266146	0.776612	0.919766	0.342701	0.372596
52° 20′	0.710622	0.263297	0.771959	0.920544	0.341076	0.370516
52° 30′	0.706951	0.260472	0.767327	0.921316	0.339454	0.368444
52° 40′	0.703289	0.257671	0.762716	0.922085	0.337834	0.366380
52° 50′	0.699634	0.254892	0.758125	0.922848	0.336214	0.364322
53°	0.695988	0.252136	0.753554	0.923607	0.334596	0.362271
53° 10′	0.692350	0.249402	0.749003	0.924362	0.332979	0.360226
53° 20′	0.688719	0.246691	0.744472	0.925111	0.331364	0.358188
53° 30′	0.685097	0.244003	0.739961	0.925856	0.329751	0.356158
53° 40′	0.681482	0.241336	0.735469	0.926595	0.328138	0.354134
53° 50′	0.677875	0.238691	0.730996	0.927331	0.326528	0.352117
54°	0.674276	0.236068	0.726542	0.928061	0.324920	0.350106
54° 10′	0.670684	0.233466	0.722107	0.928787	0.323312	0.348101
54° 20′	0.667100	0.230886	0.717691	0.929509	0.321707	0.346104
54° 30′	0.663523	0.228327	0.713293	0.930225	0.320103	0.344113
54° 40′	0.659953	0.225789	0.708913	0.930937	0.318500	0.342129
54° 50′	0.656391	0.223271	0.704551	0.931644	0.316898	0.340150
55°	0.652837	0.220774	0.700207	0.932347	0.315299	0.338178
55° 10′	0.649289	0.218298	0.695881	0.933046	0.313700	0.336211
55° 20′	0.645748	0.215842	0.691572	0.933740	0.312103	0.334251
55° 30′	0.642215	0.213406	0.687281	0.934430	0.310508	0.332296
55° 40′	0.638689	0.210990	0.683007	0.935115	0.308914	0.330348
55° 50′	0.635170	0.208594	0.678749	0.935795	0.307322	0.328407
56°	0.631658	0.206218	0.674509	0.936471	0.305731	0.326471
56° 10′	0.628153	0.203861	0.670285	0.937143	0.304141	0.324540
56° 20′	0.624655	0.201523	0.666077	0.937811	0.302552	0.322615
56° 30′	0.621163	0.199205	0.661886	0.938474	0.300965	0.320697
56° 40′	0.617678	0.196906	0.657710	0.939134	0.299380	0.318784
56° 50′	0.614200	0.194625	0.653551	0.939789	0.297796	0.316876
57°	0.610728	0.192363	0.649408	0.940439	0.296213	0.314973
57° 10′	0.607262	0.190120	0.645280	0.941084	0.294632	0.313077
57° 20′	0.603804	0.187895	0.641167	0.941726	0.293052	0.311186
57° 30′	0.600352	0.185689	0.637070	0.942363	0.291473	0.309301
57° 40′	0.596906	0.183501	0.632988	0.942996	0.289896	0.307420
57° 50′	0.593466	0.181331	0.628921	0.943625	0.288320	0.305545
58°	0.590033	0.179178	0.624869	0.944250	0.286745	0.303675
58° 10′	0.586606	0.177044	0.620832	0.944870	0.285172	0.301811
58° 20′	0.583185	0.174927	0.616809	0.945486	0.283600	0.299951
58° 30′	0.579771	0.172828	0.612801	0.946099	0.282029	0.298097
58° 40′	0.576362	0.170746	0.608807	0.946708	0.280460	0.296247
58° 50′	0.572959	0.168681	0.604827	0.947312	0.278892	0.294403
59°	0.569563	0.166633	0.600861	0.947913	0.277325	0.292563
59° 10′	0.566172	0.164603	0.596908	0.948509	0.275759	0.290729
59° 20′	0.562787	0.162589	0.592970	0.949100	0.274194	0.288900
59° 30′	0.559408	0.160592	0.589045	0.949687	0.272631	0.287075
59° 40′	0.556035	0.158612	0.585134	0.950271	0.271069	0.285255
59° 50′	0.552667	0.156648	0.581235	0.950851	0.269509	0.283440

φ	x_1	y_1	l_1	$\frac{x}{l}$	$\frac{y}{l}$	$\frac{y}{x}$
60°	0.549306	0.154701	0.577350	0.951428	0.267949	0.281629
60° 10′	0.545950	0.152769	0.573478	0.951999	0.266390	0.279823
60° 20′	0.542600	0.150854	0.569619	0.952565	0.264833	0.278021
60° 30′	0.539255	0.148956	0.565773	0.953128	0.263278	0.276225
60° 40′	0.535915	0.147073	0.561939	0.953688	0.261723	0.274433
60° 50′	0.532581	0.145206	0.558118	0.954245	0.260170	0.272644
61°	0.529253	0.143354	0.554309	0.954797	0.258617	0.270861
61° 10′	0.525930	0.141518	0.550513	0.955345	0.257067	0.269082
61° 20′	0.522612	0.139698	0.546728	0.955889	0.255517	0.267308
61° 30′	0.519299	0.137893	0.542956	0.956429	0.253968	0.265537
61° 40′	0.515992	0.136103	0.539195	0.956966	0.252419	0.263771
61° 50′	0.512690	0.134329	0.535447	0.957499	0.250873	0.262009
62°	0.509392	0.132570	0.531709	0.958028	0.249328	0.260251
62° 10′	0.506100	0.130826	0.527984	0.958553	0.247784	0.258498
62° 20′	0.502814	0.129097	0.524270	0.959074	0.246241	0.256748
62° 30′	0.499532	0.127382	0.520567	0.959591	0.244699	0.255003
62° 40′	0.496255	0.125682	0.516876	0.960105	0.243157	0.253261
62° 50′	0.492983	0.123997	0.513195	0.960615	0.241617	0.251523
63°	0.489716	0.122326	0.509525	0.961121	0.240078	0.249790
63° 10′	0.486453	0.120670	0.505867	0.961624	0.238540	0.248060
63° 20′	0.483196	0.119028	0.502219	0.962122	0.237004	0.246335
63° 30′	0.479943	0.117400	0.498582	0.962616	0.235469	0.244613
63° 40′	0.476695	0.115787	0.494955	0.963107	0.233934	0.242895
63° 50′	0.473451	0.114187	0.491339	0.963595	0.232400	0.241180
64°	0.470213	0.112602	0.487733	0.964079	0.230868	0.239470
64° 10′	0.466979	0.111030	0.484137	0.964559	0.229337	0.237763
64° 20′	0.463749	0.109473	0.480551	0.965035	0.227806	0.236060
64° 30′	0.460524	0.107929	0.476976	0.965508	0.226277	0.234361
64° 40′	0.457303	0.106398	0.473410	0.965978	0.224748	0.232664
64° 50′	0.454087	0.104881	0.469854	0.966444	0.223221	0.230971
65°	0.450875	0.103378	0.466308	0.966906	0.221695	0.229282
65° 10′	0.447668	0.101888	0.462771	0.967364	0.220169	0.227597
65° 20′	0.444465	0.100411	0.459244	0.967819	0.218645	0.225915
65° 30′	0.441266	0.098948	0.455726	0.968271	0.217121	0.224236
65° 40′	0.438072	0.097498	0.452218	0.968718	0.215599	0.222561
65° 50′	0.434881	0.096060	0.448719	0.969162	0.214077	0.220889
66°	0.431695	0.094636	0.445229	0.969602	0.212557	0.219221
66° 10′	0.428513	0.093225	0.441748	0.970039	0.211037	0.217555
66° 20′	0.425335	0.091827	0.438276	0.970473	0.209518	0.215893
66° 30′	0.422161	0.090441	0.434812	0.970903	0.208000	0.214234
66° 40′	0.418991	0.089068	0.431358	0.971329	0.206483	0.212578
66° 50′	0.415825	0.087708	0.427912	0.971752	0.204967	0.210925
67°	0.412663	0.086360	0.424475	0.972172	0.203452	0.209276
67° 10′	0.409504	0.085025	0.421046	0.972588	0.201938	0.207630
67° 20′	0.406350	0.083703	0.417626	0.973001	0.200425	0.205986
67° 30′	0.403200	0.082392	0.414214	0.973410	0.198913	0.204346
67° 40′	0.400053	0.081094	0.410810	0.973816	0.197401	0.202708
67° 50′	0.396910	0.079809	0.407414	0.974219	0.195891	0.201074

v	x_1	y_1	l_1	$\frac{x}{l}$	$\frac{y}{l}$	$\frac{y}{x}$
68°	0.393771	0.078535	0.404026	0.974618	0.194381	0.199443
68° 10′	0.390636	0.077273	0.400646	0.975013	0.192872	0.197814
68° 20′	0.387504	0.076024	0.397275	0.975405	0.191363	0.196189
68° 30′	0.384375	0.074786	0.393911	0.975794	0.189856	0.194566
68° 40′	0.381251	0.073561	0.390554	0.976179	0.188350	0.192946
68° 50′	0.378130	0.072347	0.387205	0.976561	0.186844	0.191328
69°	0.375012	0.071145	0.383864	0.976940	0.185339	0.189714
69° 10′	0.371898	0.069955	0.380530	0.977316	0.183835	0.188102
69° 20′	0.368787	0.068776	0.377204	0.977688	0.182332	0.186493
69° 30′	0.365680	0.067609	0.373885	0.978056	0.180830	0.184887
69° 40′	0.362576	0.066454	0.370573	0.978421	0.179328	0.183282
69° 50′	0.359476	0.065310	0.367268	0.978783	0.177827	0.181681
70°	0.356379	0.064178	0.363970	0.979142	0.176327	0.180083
70° 10′	0.353285	0.063057	0.360680	0.979497	0.174828	0.178488
70° 20′	0.350194	0.061947	0.357396	0.979849	0.173330	0.176894
70° 30′	0.347106	0.060848	0.354119	0.980198	0.171832	0.175303
70° 40′	0.344022	0.059762	0.350848	0.980544	0.170335	0.173715
70° 50′	0.340941	0.058686	0.347585	0.981225	0.168838	0.172128
71°	0.337863	0.057621	0.344328	0.983487	0.167343	0.170544
71° 10′	0.334788	0.056567	0.341077	0.981561	0.165848	0.168963
71° 20′	0.331716	0.055524	0.337833	0.981893	0.164354	0.167385
71° 30′	0.328647	0.054492	0.334595	0.982223	0.162860	0.165808
71° 40′	0.325581	0.053471	0.331364	0.982549	0.161366	0.164233
71° 50′	0.322518	0.052462	0.328139	0.982872	0.159874	0.162661
72°	0.319458	0.051462	0.324920	0.983192	0.158386	0.161092
72° 10′	0.316401	0.050474	0.321707	0.983508	0.156895	0.159526
72° 20′	0.313347	0.049496	0.318500	0.983821	0.155404	0.157961
72° 30′	0.310295	0.048529	0.315299	0.984131	0.153914	0.156398
72° 40′	0.307247	0.047573	0.312104	0.984438	0.152425	0.154836
72° 50′	0.304201	0.046627	0.308914	0.984742	0.150938	0.153277
73°	0.301158	0.045692	0.305731	0.985042	0.149451	0.151721
73° 10′	0.298117	0.044767	0.302553	0.985340	0.147964	0.150167
73° 20′	0.295080	0.043853	0.299380	0.985634	0.146478	0.148614
73° 30′	0.292045	0.042949	0.296214	0.985925	0.144993	0.147063
73° 40′	0.289012	0.042055	0.293052	0.986213	0.143508	0.145514
73° 50′	0.285982	0.041172	0.289896	0.986498	0.142024	0.143968
74°	0.282955	0.040300	0.286745	0.986780	0.140541	0.142424
74° 10′	0.279930	0.039437	0.283600	0.987058	0.139058	0.140881
74° 20′	0.276907	0.038585	0.280460	0.987334	0.137576	0.139341
74° 30′	0.273887	0.037742	0.277325	0.987606	0.136094	0.137802
74° 40′	0.270870	0.036910	0.274195	0.987875	0.134613	0.136264
74° 50′	0.267855	0.036088	0.271069	0.988142	0.133132	0.134729
75°	0.264842	0.035276	0.267949	0.988405	0.131652	0.133197
75° 10′	0.261832	0.034474	0.264834	0.988665	0.130173	0.131666
75° 20′	0.258824	0.033682	0.261723	0.988922	0.128695	0.130136
75° 30′	0.255818	0.032900	0.258618	0.989175	0.127216	0.128608
75° 40′	0.252815	0.032128	0.255517	0.989426	0.125738	0.127082
75° 50′	0.249814	0.031366	0.252420	0.989674	0.124261	0.125558

v	x_1	y_1	l_1	$\frac{x}{l}$	$\frac{y}{l}$	$\frac{y}{x}$
76°	0.246814	0.030614	0.249328	0.989919	0.122785	0.124035
76° 10′	0.243817	0.029871	0.246241	0.990160	0.121309	0.122514
76° 20′	0.240822	0.029138	0.243158	0.990400	0.119833	0.120994
76° 30′	0.237830	0.028415	0.240079	0.990635	0.118358	0.119476
76° 40′	0.234840	0.027702	0.237004	0.990867	0.116883	0.117960
76° 50′	0.231851	0.026998	0.233934	0.991097	0.115410	0.116446
77°	0.228865	0.026304	0.230868	0.991323	0.113936	0.114933
77° 10′	0.225881	0.025620	0.227806	0.991547	0.112462	0.113421
77° 20′	0.222898	0.024945	0.224749	0.991767	0.110990	0.111911
77° 30′	0.219918	0.024280	0.221695	0.991984	0.109518	0.110403
77° 40′	0.216939	0.023624	0.218645	0.992199	0.108046	0.108896
77° 50′	0.213962	0.022978	0.215599	0.992410	0.106575	0.107391
78°	0.210988	0.022341	0.212556	0.992619	0.105105	0.105886
78° 10′	0.208015	0.021713	0.209518	0.992825	0.103634	0.104383
78° 20′	0.205044	0.021095	0.206483	0.993027	0.102164	0.102881
78° 30′	0.202074	0.020487	0.203452	0.993227	0.100695	0.101382
78° 40′	0.199107	0.019887	0.200425	0.993423	0.099226	0.099883
78° 50′	0.196141	0.019297	0.197401	0.993617	0.097758	0.098386
79°	0.193177	0.018717	0.194380	0.993807	0.096289	0.096889
79° 10′	0.190214	0.018145	0.191363	0.993995	0.094822	0.095394
79° 20′	0.187253	0.017583	0.188350	0.994180	0.093354	0.093900
79° 30′	0.184294	0.017030	0.185339	0.994362	0.091887	0.092408
79° 40′	0.181336	0.016486	0.182332	0.994540	0.090420	0.090916
79° 50′	0.178380	0.015952	0.179328	0.994716	0.088954	0.089427
80°	0.175426	0.015426	0.176327	0.994890	0.087488	0.087938
80° 10′	0.172473	0.014910	0.173329	0.995060	0.086023	0.086450
80° 20′	0.169521	0.014403	0.170334	0.995227	0.084559	0.084964
80° 30′	0.166571	0.013905	0.167343	0.995391	0.083094	0.083479
80° 40′	0.163623	0.013416	0.164354	0.995552	0.081629	0.081994
80° 50′	0.160676	0.012936	0.161368	0.995711	0.080165	0.080510
81°	0.157730	0.012465	0.158384	0.995866	0.078702	0.079028
81° 10′	0.154785	0.012003	0.155404	0.996017	0.077238	0.077547
81° 20′	0.151842	0.011550	0.152426	0.996167	0.075775	0.076068
81° 30′	0.148900	0.011106	0.149451	0.996314	0.074312	0.074588
81° 40′	0.145960	0.010671	0.146478	0.996459	0.072850	0.073109
81° 50′	0.143020	0.010245	0.143508	0.996600	0.071387	0.071631
82°	0.140082	0.009827	0.140541	0.996737	0.069926	0.070155
82° 10′	0.137146	0.009419	0.137576	0.996872	0.068466	0.068680
82° 20′	0.134210	0.009020	0.134613	0.997004	0.067004	0.067205
82° 30′	0.131275	0.008629	0.131653	0.997134	0.065543	0.065731
82° 40′	0.128342	0.008247	0.128694	0.997261	0.064083	0.064259
82° 50′	0.125409	0.007874	0.125738	0.997385	0.062624	0.062788
83°	0.122478	0.007510	0.122785	0.997505	0.061164	0.061317
83° 10′	0.119548	0.007154	0.119833	0.997622	0.059703	0.059846
83° 20′	0.116619	0.006808	0.116883	0.997739	0.058243	0.058375
83° 30′	0.113691	0.006470	0.113936	0.997850	0.056784	0.056906
83° 40′	0.110763	0.006141	0.110990	0.997958	0.055325	0.055438
83° 50′	0.107837	0.005820	0.108046	0.998064	0.053867	0.053972

φ	x_1	y_1	l_1	$\frac{x}{l}$	$\frac{y}{l}$	$\frac{y}{x}$
84°	0.104912	0.005508	0.105104	0.998169	0.052408	0.052505
84° 10′	0.101987	0.005205	0.102164	0.998268	0.050949	0.051038
84° 20′	0.099064	0.004911	0.099226	0.998367	0.049491	0.049572
84° 30′	0.096141	0.004625	0.096289	0.998462	0.048032	0.048106
84° 40′	0.093219	0.004348	0.093354	0.998554	0.046575	0.046642
84° 50′	0.090298	0.004080	0.090421	0.998642	0.045119	0.045180
85°	0.087377	0.003820	0.087489	0.998728	0.043662	0.043717
85° 10′	0.084458	0.003569	0.084558	0.998812	0.042204	0.042253
85° 20′	0.081539	0.003326	0.081629	0.998893	0.040746	0.040791
85° 30′	0.078621	0.003092	0.078702	0.998971	0.039290	0.039333
85° 40′	0.075704	0.002867	0.075776	0.999046	0.037834	0.037871
85° 50′	0.072787	0.002650	0.072851	0.999118	0.036378	0.036410
86°	0.069870	0.002442	0.069927	0.99919	0.03492	0.03495
86° 10′	0.066954	0.002242	0.067004	0.99925	0.03346	0.03349
86° 20′	0.064039	0.002051	0.064083	0.99932	0.03201	0.03203
86° 30′	0.061125	0.001869	0.061163	0.99938	0.03055	0.03057
86° 40′	0.058211	0.001695	0.058243	0.99944	0.02910	0.02911
86° 50′	0.055297	0.001529	0.055325	0.99949	0.02764	0.02765
87°	0.052384	0.001372	0.052408	0.99954	0.02618	0.02619
87° 10′	0.049471	0.001224	0.049491	0.99959	0.02473	0.02474
87° 20′	0.046559	0.001084	0.046576	0.99964	0.02327	0.02328
87° 30′	0.043647	0.000953	0.043661	0.99968	0.02182	0.02183
87° 40′	0.040736	0.000830	0.040747	0.99972	0.02036	0.02037
87° 50′	0.037825	0.000715	0.037834	0.99976	0.01891	0.01892
88°	0.034914	0.000609	0.034921	0.99980	0.01745	0.01746
88° 10′	0.032003	0.000512	0.032009	0.99983	0.01600	0.01601
88° 20′	0.029093	0.000423	0.029097	0.99986	0.01455	0.01455
88° 30′	0.026183	0.000343	0.026186	0.99989	0.01309	0.01309
88° 40′	0.023273	0.000271	0.023275	0.99991	0.01163	0.01163
88° 50′	0.020364	0.000207	0.020365	0.99993	0.01017	0.01017
89°	0.017454	0.000152	0.017455	0.99995	0.00873	0.00873
89° 10′	0.014545	0.000106	0.014545	0.99997	0.00727	0.00727
89° 20′	0.011636	0.000068	0.011636	0.99998	0.00582	0.00582
89° 30′	0.008727	0.000038	0.008727	0.99999	0.00436	0.00436
89° 40′	0.005818	0.000017	0.005818	1.00000	0.00290	0.00290
89° 50′	0.002909	0.000004	0.002909	1.00000	0.00144	0.00144
90°	0.000000	0.000000	0.000000	1.00000	0.00000	0.00000

and the unknown element will then result by multiplying the corresponding element of the unit catenary by c. Thus:

$$x = cx_1, \quad y = cy_1, \quad l = cl_1.$$

Two independent calculations of the unknown quantity are always available and their comparison furnishes a veri-

fication. Thus, if x and y are given,

$$l = cl_1 = \frac{x}{x_1} l_1 = \frac{y}{y_1} l_1$$

After solution, a further check may be obtained by using the fundamental catenary equation

$$(y + c)^2 = l^2 + c^2$$

which, for ease in computation, may be reduced to:

$$y(y + 2c) = l^2.$$

The three equations from which the table is computed are

$$x_1 = \text{hyp. log. cot. } \tfrac{1}{2}v, \tag{1}$$

$$y_1 = \left(\frac{1}{\sin. v} - 1\right) = \text{excosec. } v, \tag{2}$$

$$l_1 = \text{cot. } v. \tag{3}$$

The correctness of these equations may be shown as follows:

If we assume (1) to be true, we have

$$x_1 = \frac{\log_{.10} \text{cot. } \tfrac{1}{2}v}{\log_{.10} \epsilon},$$

whence $x_1 \log_{.10} \epsilon = \log_{.10} \text{cot. } \tfrac{1}{2}v$ or

$$\epsilon^{x_1} = \text{cot. } \tfrac{1}{2}v \quad \text{and} \quad \epsilon^{-x_1} = \frac{1}{\text{cot. } \tfrac{1}{2}v}.$$

Substituting in the fundamental equation for the unit catenary

$$y_1 = \tfrac{1}{2}(\epsilon^{x_1} + \epsilon^{-x_1}) - 1, \tag{4}$$

we obtain

$$y_1 = \frac{1}{2}\left(\text{cot. } \tfrac{1}{2}v + \frac{1}{\text{cot. } \tfrac{1}{2}v}\right) - 1. \tag{5}$$

We have now substituted in (4) a value of x_1 obtained by assuming (1) to be a true relation. Hence if this assumption is correct, and if (2) is also correct, it must follow that (5) is identical with (2).

From (5)

$$y_1 = \frac{1}{2}\left(\frac{\cos.\ \frac{1}{2}v}{\sin.\ \frac{1}{2}v} + \frac{\sin.\ \frac{1}{2}v}{\cos.\ \frac{1}{2}v}\right) - 1,$$

$$y_1 = \frac{1}{2}\left(\frac{\cos.^2\ \frac{1}{2}v + \sin.^2\ \frac{1}{2}v}{\sin.\ \frac{1}{2}v \cos.\ \frac{1}{2}v}\right) - 1,$$

$$y_1 = \frac{1}{2}\left(\frac{1}{\frac{1}{2}\sin.\ v}\right) - 1,$$

$$y_1 = \left(\frac{1}{\sin.\ v} - 1\right),$$

which is identical with (2). Hence (1) and (2) are true relations. The correctness of (3) is easily shown by consideration of the forces at A in Fig. 1. Since the weight of the catenary is 1.0 per linear unit, the vertical reaction R equals l_1.

But

$$\frac{R}{c} = \cot.\ v = \frac{l_1}{c}$$

and since $c = 1.0$, $l_1 = \cot.\ v$.

Results obtained by use of this table are considered to be quite close enough for all requirements in the practical erection of the cable in the centre span of a suspension bridge. For a span of 4000 ft. and a sag of 500 ft., the discrepancy in l as compared with computation by the catenary equation $(y + c)^2 = l^2 + c^2$ was less than 1/2 inch. For a span of 1632′ and with sags of 100′, 120′, 200′ and 350′ respectively, discrepancies were less than 1/8″ for all cases except one with a sag of 100′ where x and l were given, in which case it was less than 1/2″. These differences in view of the large dimensions considered would appear to be quite negligible.

For use in side spans of a suspension bridge, where the location of the vertex is not given, the table may be used to some advantage if c is known, but a tentative process is generally necessary. If c is not known, however, the table is not readily applicable to side spans where the location of the vertex is unknown.

It is of interest to note that, if x and y are given, the solution for l by other methods in general use is quite laborious, whereas by the table no greater difficulty is encountered than

when any other of the three lengths is sought. Example showing application of the foregoing method:

Assume $x = 1000'$, $y = 200'$, $\frac{y}{x} = 0.200000$.

From table, v lies between 67° 50′ and 68° 0′

$$v = 67^\circ\ 50' \ldots\ldots \frac{y}{x} = 0.201074 \qquad 0.201074,$$

$$v = 68^\circ\ 0' \ldots\ldots \frac{y}{x} = \frac{0.199443}{0.001631} \qquad \frac{0.200000}{0.001074}.$$

Interpolating ratio $= \frac{1074}{1631}$

$$\frac{1074}{1631} \times 600'' = 395'' = 6'\ 35''.$$

Hence $v = 67^\circ\ 56'\ 35''$

$$v = 67^\circ\ 50' \ldots\ldots \frac{x_1}{0.396910} \quad \frac{y_1}{0.079809} \quad \frac{l_1}{0.407414},$$

$$v = 68^\circ\ 0' \ldots\ldots \frac{0.393771}{0.003139} \quad \frac{0.078535}{0.001274} \quad \frac{0.404026}{0.003388}.$$

$$\frac{1074}{1631} \times 3139 = \begin{array}{r} 0.396910 \\ 2067 \\ \hline x_1 = 0.394843 \end{array}$$

$$\frac{1074}{1631} \times 1274 = \begin{array}{r} 0.079809 \\ 839 \\ \hline y_1 = 0.078970 \end{array}$$

$$\frac{1074}{1631} \times 3388 = \begin{array}{r} 0.407414 \\ 2231 \\ \hline l_1 = 0.405183 \end{array}$$

$$c = \frac{x}{x_1} = \frac{1000}{0.394843} = 2532.652';$$

or

$$c = \frac{y}{y_1} = \frac{200}{0.078970} = 2532.608',$$

$$l = \frac{x}{x_1} l_1 = 1026.188'$$

or

$$l = \frac{y}{y_1} l_1 = 1026.170'.$$

Check by $y(y + 2c) = l^2$

say $2c = 5065.304$,
$200\ (5265.304) = l^2$,
$l^2 = 1053060.8$,
$l = 1026.187'$

or say $2c = 5065.216$,
$200\ (5265.216) = l^2$,
$l^2 = 1053043.2$,
$l = 1026.179'$.

The greatest difference in computed values of l is 0.22″.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

INTERNATIONAL COMMITTEE ON WEIGHTS AND MEASURES.

The International Committee on Weights and Measures held its regular biennial meeting at Sevres and Paris, France, June 23 to 29, 1937. Its most important actions were further steps toward the introduction of electrical units based upon absolute measurements, that is, derived directly from the fundamental mechanical units, and a decision to establish a new system of photometric units to supersede the two systems now in use in different countries. Both of these changes are intended to take effect January 1, 1940.

National laboratories in several countries are making experimental determinations of the absolute values of the electrical units. The results of such determinations are brought together at the International Bureau of Weights and Measures in the form of values assigned to standard cells and ohm standards sent from the National laboratories. In establishing the units on the new basis all such determinations reported before the end of 1938 will be considered.

In 1935 the International Committee issued a table of the ratios existing between the present International units and the corresponding absolute units, stated to 4 decimal places. (*Technical News Bulletin 225;* January, 1936.) Determinations now reported seem to justify an estimate carried one decimal place further, so that manufacturers of high precision standards and others interested can prepare for the change of units. Accordingly, the International Committee now gives the following probable relations:

1 mean international ohm = 1.000 48 absolute ohms,

1 mean international volt = 1.000 36 absolute volts.

The first of these values appears to be exact to 2 or 3 units in the last place given; the second to a few units in that place.

The "mean international" ohm and volt are the means of the units maintained by six national laboratories, starting

* Communicated by the Director.

from the values found in 1935 as a base. At that time the French laboratory adopted the mean of the other five, and since then the Russian laboratory has adjusted its units to the mean. There has also been a slight drift of relative values. As a result of comparisons made in December, 1936, and January, 1937, the International Bureau reports the following departures of the Units of the several countries from the mean units as established in 1935.

Departure of National Units from Mean International Ohm and Volt.
(In parts per million.)

Country	In 1935		In 1936–7	
	Ohm	Volt	Ohm	Volt
France	Adopted mean		+ 1	+ 1
Germany	+10	− 4	+ 7	− 7
Great Britain	− 4	+ 5	− 4	+ 8
Japan	−11	− 2	−10	+ 1
U. S. S. R.	+11	+13	0	− 6
United States	− 6	−12	− 4	−10

The new system of photometric units to be established will be derived from a primary standard proposed and developed by the National Bureau of Standards. This is a black-body radiator operated at the temperature of freezing platinum of specified purity. The magnitude of the units in the new system will be fixed by taking the brightness of the primary standard as exactly 60 candles per square centimeter.

For sources of light differing in color from the primary standard the photometric values will be determined by methods based upon the spectral luminosity factors (formerly called visibility factors) established at the Bureau in 1923 and since then adopted by various national and international bodies. For the immediate purpose of calibrating incandescent lamps or secondary standards at temperatures above that of the primary standard, use will be made of blue filters which have been chosen to produce a color match in the photometric field when they are interposed between the photometer and the standard operating at the lower temperature.

In order to insure uniformity between countries in setting up the new standards, groups of lamps of each general type

will be prepared by each national laboratory and sent to the National Physical Laboratory of Great Britain for comparison.

The units to be established will be called the "new candle," "new lumen," etc., with appropriate translation into other languages, in the expectation that after a few years the adjective "new" will be dropped in ordinary use of the terms.

For a number of years the International Committee has had advisory committees on electricity and on photometry, through which it obtains the advantages of organized collaboration with the several national standardizing laboratories and with individual experts in those special fields. It has now decided to form a similar Advisory Committee on Thermometry.

PORTABLE PHOTOELECTRIC TIMING APPARATUS.

The timing of intervals of a few seconds to several minutes is usually done with a stopwatch. Such measurements, although sufficiently exact for many purposes, are subject to errors because of variation in rate of the watch, errors in the starting and stopping of the indicating mechanism, and personal errors of the observer. In an attempt to measure the rate of flow of water with an accuracy of approximately 0.1 per cent. during short intervals the need of more precise equipment was felt. A timer consisting of a photoelectric relay, a chronograph, and a chronometer was, therefore, constructed by F. C. Morey of the Bureau's hydraulic laboratory.

The apparatus is arranged so that when the flow of water is diverted from the waste trough into the collecting tank a target on the diverter momentarily breaks a beam of light falling on the photocell. The photoelectric relay thus sends an electrical impulse to a pen on the chronograph. This causes a mark to appear on the moving paper tape. Continuous electrical time signals from the chronometer are received by another pen on the chronograph making similar marks every half second on the same tape. It is thus possible to determine the number of seconds elapsed between successive breaks in the light beam, which, in turn, denote the starting and stopping of the collecting of water in the weigh tank.

Tests on the chronometer and chronograph by comparison with time signals from an astronomical clock of known rate

showed that the signals from the chronometer did not depart from the former by more than 0.0498 second per hour and did not deviate from their average rate by more than 0.0158 second per hour. The chronometer thus provides a source of highly accurate time signals.

In actual use the timing equipment has made possible the determination of the rate of flow of water during intervals as short as 20 seconds with such a degree of precision that in eleven trials with a constant rate of flow the greatest deviation from the average rate amounted to only 0.13 per cent.

Other advantages possessed by the timer are portability, adaptability to many time measurement problems, permanence of record, and elimination of the personal factor.

STANDARDIZATION OF DENTAL MATERIALS.

As a result of cooperative research between the Bureau and the American Dental Association, standards have been developed for nine dental materials. Lists of products which comply with these standards are furnished to dentists after the respective manufacturers have certified that their materials meet the standard requirements. Samples of all certified products are tested by research associates stationed at the Bureau to prevent improper use of the certification privilege.

Scientific research on dental materials has a direct relation to the health of the people of the United States, and the present program reaches from the manufacturer to the consumer and is mutually helpful to all concerned.

SEPARATION OF THE THREE METHYLOCTANES FROM MIDCONTINENT PETROLEUM.

The isolation of the three methyloctanes from petroleum has been accomplished for the first time by Joseph D. White and Augustus R. Glasgow, Jr., of the Bureau's Chemistry Division. The work is a continuation of that on the separation, identification, and determination of the constituents of petroleum, sponsored by the American Petroleum Institute as its Research Project 6.

The methyloctanes were found closely associated with naphthenic hydrocarbons in the fraction of Oklahoma petro-

leum which distilled between 142 and 145° C., after the aromatic hydrocarbons had been removed. Together they constitute about 0.3 per cent. of the crude, the 2-, 3-, and 4-methyloctane being present in the proportions of 3, 1, and 1.

In all, the methyloctane fraction contained not less than 7 compounds. These have been separated from one another by physical means alone. *o*-Xylene was extracted with liquid sulphur dioxide and silica gel, the naphthenes were removed by distillation either at reduced pressure or with admixture of glacial acetic acid. The residual paraffinic fraction yielded, at once, 2-methyloctane on crystallization from solvent dichlorodifluoromethane. Redistillation of the mother liquid produced concentrates of the 3- and 4-methyloctane which, because of their high viscosity when cooled, had to be crystallized from solvent methane, a liquid with very low viscosity, in order to separate them in a nearly pure condition.

The isolated methyloctanes were identified by their physical properties. Those obtained were boiling point, freezing point, density, refractive index, and critical solution temperature in aniline. A characteristic property of the 3- and 4-methyloctane was the pronounced undercooling required to induce them to crystallize. This phenomenon is associated with their optical isomerism. In such cases the presence of two varieties of molecules strongly militates against crystallization.

Thus far, 5 of the 35 isomeric hydrocarbons having the formula C_9H_{20} have been isolated from the petroleum, namely, the three methyloctanes, *n*-nonane boiling at 150.7° C., and 2, 6-dimethylheptane boiling at 135.2° C. There are indications that a few other nonanes are present in detectable amounts, but the complete analysis of the petroleum will reveal only a fraction of the number which conceivably could be present.

RP1033 in the October number of the *Journal of Research* gives the official report of this work.

TRANSPARENT PLASTICS FOR AIRCRAFT WINDOWS.

The utilization of transparent synthetic plastics for windows has been the goal of many research workers because of the fragility and hazardous nature of glass. Cost con-

siderations, as well as low scratch resistance, have limited the use of organic plastic windows to removable curtains for automobiles and wire-reinforced products with a high ultraviolet transmission. The aircraft industry, however, has stimulated the development of windshields from transparent plastics. These save half the weight and can be bent to conform to streamline design.

Cellulose nitrate (celluloid) and cellulose acetate, which has found an important application in transparent form as safety or flame-resistant film, have both been used as aircraft windshields. The cellulose is usually obtained from cotton, but wood and stalks of wheat, corn, and other grains can be used. During 1936 a type of synthetic resin which can be made from alcohol or acetone was introduced in this country in transparent sheet form. Technically, these transparent resins are classed as esters of acrylic and methacrylic acids and are distantly related to glycerol.

The National Advisory Committee for Aeronautics established a project at the Bureau to study the suitability of synthetic resins and cellulose plastics for aircraft windshields. The following types of transparent plastics were found to be available commercially or experimentally: cellulose nitrate, cellulose acetate, cellulose acetobutyrate, ethylcellulose, acrylate and methacrylate esters, vinyl chloride-acetate, vinyl acetal, glyceryl phthalate, styrene, and phenol-formaldehyde. The behavior of these materials was determined with respect to light transmission; freedom from haze, surface imperfections and constituents which reduce or distort vision; resistance to weathering and to surface abrasion; impact strength; dimensional stability; resistance to the action of water and cleaning fluids; bursting strength at normal and low temperatures; and flammability.

The results so far obtained in this investigation are given in RP1031, to be published in the *Journal of Research* for October. Cellulose acetate plastic was found to have excellent impact strength, bursting strength, and flexibility, but the commercial products tested varied considerably in resistance to weathering, and all were subject to marked shrinkage in one year's time. The shrinkage produces warping and sets up strains in the plastic sheets, which cause them to craze and

crack. These strains are believed to be the cause of the spontaneous cracking of cellulose acetate windshields after they have been in service for six months or longer. This is particularly true of windshields exposed to the low temperatures encountered at high altitudes. A great deal of variation was observed in the weathering resistance between cellulose acetate sheets received from different manufacturers, and also between different lots of the material from the same manufacturer.

The acrylate resin plastic was found to be remarkably transparent, more stable to light and weathering and more resistant to scratching than cellulose acetate, but it is deficient in impact strength and flexibility. Surface crazing of the acrylate resins was noted after one year's exposure outdoors, and also after storage for a similar period. It is claimed, however, that a method of processing has been developed which eliminates this tendency.

Other transparent plastics, such as cellulose nitrate, ethylcellulose, vinyl chloride-acetate resin, and vinyl acetal resins, failed in resistance to weathering after approximately three months. Glyceryl-phthalate, styrene and phenol-formaldehyde resin plastics discolored markedly on exposure to sunlight or ultra-violet light from a carbon arc lamp, and also lacked flexibility. A sample of cellulose acetobutyrate was practically unchanged after 12 months' exposure. With the exception of the cellulose nitrate, cellulose acetate, and acrylate resin plastics, the materials tested were of an experimental nature and were not recommended for use on aircraft. Many of the undesirable properties observed for these experimental materials will undoubtedly be eliminated in the course of development, and it is not improbable that some of them will later become available in a form suitable for windshield use.

Pending the results of further tests on samples of cellulose acetate, acrylate resin, and other plastics, which have been prepared by the manufacturers using modified compositions and methods of processing to overcome the defective behavior noted during the course of this investigation, it is concluded that the problem of choosing between cellulose acetate and acrylate resin plastics for aircraft windows at present appears

to hinge on the required impact strength. If a relatively high strength is necessary, the cellulose acetate sheets are much superior to the acrylate resin. However, if this is not essential, then the superior clarity and weathering resistance of the acrylate resin makes it more desirable. Both the cellulose acetate and the acrylate resin have the advantages of being lighter in weight than glass and of being readily fitted to curved openings.

GLASS-LINED HYPO TANKS.

In *Technical News Bulletin 223* (November, 1935), a reference was made to some studies of the action of hypo solutions on stone tanks frequently used in photographic shops. Unless a careful selection of the stone is made for such tanks, they are not apt to prove satisfactory because of the severe conditions arising from crystallization of the hypo salts within the pores. A more complete description of the studies was published in *J. Research* N.B.S., **16**, 161 (February, 1936), (RP864), in which a specification is suggested for obtaining suitable stone for this purpose. As the specification is necessarily quite stringent, there are only a limited number of materials available that will meet the requirements.

In view of these considerations, it was thought possible to design a tank that could be made at moderate cost, and for which it would be feasible to utilize a large variety of stone products. Hence a small test tank was designed by D. W. Kessler of slate with a glass lining. The slabs were fastened together with bolts without any special effort to secure tight joints. Five sheets of double thickness window pane glass were then cut to fit the inside of the tank. These were sealed in place by heating the slate, the glass, and a high melting asphalt to a temperature sufficient to reduce the asphalt to a thin consistency. The interior of the slate tank was then coated with the liquid asphalt and the glass slabs fitted in place. When the materials had cooled, the tank was put under test by filling half full of a standard hypo solution. It has now been exposed to the solution for one year and is still in perfect condition.

Slate was chosen for this purpose as being probably one of the most economical types of stone for such use. It is

also a material that would show early disintegration where freely exposed to the action of hypo solution, hence it affords an excellent material upon which to conduct such a test. In order to obtain a comparison between the resistance of the slate under such conditions and the resistance of other materials freely exposed to the solution, several specimens were placed inside the tank partly in the solution and partly above. Most of these specimens have shown a large amount of decay or, in some cases, almost complete disintegration.

As suggested in the publications referred to above, stone hypo tanks are often coated with a bituminous paint on the inside which affords a satisfactory protection as long as the coating remains impermeable. However, when the solution once penetrates behind the coating it will soon disappear and hence renewal is necessary. In the glass-lined tank the bituminous material is exposed to the hypo solution only in the joints of the glass and the above test has indicated that under such conditions it will last for a considerable period of time.

Due to the fact that slate can be quite economically made in the form of slabs, it is believed that a glass-lined slate tank, such as described above, can be constructed at less cost than tanks of those varieties of stone which are resistant to hypo solution.

FIRE TEST OF A BUILDING COLUMN.

A steel building column encased with cinder-concrete blocks and gypsum plaster was recently tested at the Bureau for the School District of Philadelphia, Penn., to determine the fire resisting value of this construction, the given type of column fireproofing not having heretofore been subjected to fire tests.

The column, a 6 in., 30 lb. H section, with a total length of 13 ft. 1 in. and an effective length of 10 ft. 4 in., mounted with one end restrained and the other on a spherical bearing block, was subjected to a constant load of 59 tons throughout the test until failure occurred.

The block covering consisted of a shell of 3 in. hollow cinder-concrete blocks set in lime-Portland cement mortar, with a 1¼ in. space between the blocks and column flanges, which, together with the reentrant spaces between the column

flanges, was filled solidly with cinder-concrete slabs and mortar. Including a ¾ in. thickness of sanded gypsum plaster, the outside dimensions of the covering were 17⅜ by 17⅝ in.

The cinder concrete in the blocks weighed 84.6 lb./ft.³, absorbed 15.5 lb. water per cu. ft., and had average compressive strength of 425 lb./in.² The combustible carbon content was 20 per cent. of the weight of the cinder concrete, and sulphur 0.3 per cent., 0.1 as sulphur trioxide and 0.2 as sulphides.

The protected column, after being seasoned and dried to constant weight, was tested in a gas-fired furnace, the temperature of which was controlled in accordance with the time-temperature schedule of the Standard Specification for Fire Tests of Building Construction and Materials (American Standards Association A2, 1934). The expansion of the column reached its maximum at 6 hr. 56 min., and failure to support the full applied load occurred at 7 hr. 23 min. The measured temperature of the steel in the region of failure averaged 1072° F. (578° C.) when the column failed, the applied load being equivalent to an average stress of 13,200 lb./in.² of the steel area. This temperature-load relation corresponds closely with those found in tests with small specimens of structural steel under closely controlled conditions, as reported in *J. Research* N.B.S., **13**, 713, November, 1934 (RP741).

The plaster adhered to the cinder concrete over most of the area throughout the period of fire exposure, only a minor amount falling from the exposed corners. None of the block covering fell off.

Further information on the fire resistance of building columns is contained in the following Bureau publications, obtainable from the Superintendent of Documents at the prices indicated:

"Fire Tests of Building Columns," S. H. Ingberg, H. K Griffin, W. C. Robinson, and R. E. Wilson. Tech. Pap. B.S., 1921 (T184, 75¢).

"Fire Resistance of Concrete Columns," W. A. Hull and S. H. Ingberg. Tech. Pap. B.S., **18**, 635 (1924–25), (T272, 25¢).

"Fire Tests of Columns Protected with Gypsum," N. D. Mitchell. B.S. *J. Research*, **10**, 737 (1933), (RP563, 5¢).

THE FRANKLIN INSTITUTE.

MONTHLY MEETING, OCTOBER 20, 1937.

The regular monthly meeting was called to order at 8:30 o'clock by Mr. Walton Forstall, Vice-President. He announced that the minutes of the previous meeting had been published in the JOURNAL of The Institute and if there were no objections they would be approved as published. As there were no objections offered, the minutes were declared approved.

He also announced that the additions to membership since the last report were as follows:

Institute Members	69
Museum Members	115
Total	184

He then called upon the Secretary to make some further announcements.

The Secretary called attention to the Fall course of lectures of the Institute, and made special mention of the Christmas week lectures, which will be held this year on Monday, Tuesday and Wednesday, December 27, 28 and 29, immediately following Christmas. Dr. Dayton C. Miller, of Cleveland, Ohio, will be the speaker. His subject will be "Electrostatics."

The Chairman then announced that, out of consideration for the outstanding lecturer of the evening, the discussion of the amendments to the By-Laws would be postponed until after the presentation of the paper of the evening. He then introduced Dr. Leo H. Baekeland, President, Bakelite Corporation, New York, who addressed the meeting on the subject "The Human Story of Bakelite and Velox."

He sketched incidents which directed his efforts in photographic research and which finally resulted in the invention of Velox paper, a photographic process now generally adopted under various names which does away with the slow, uncertain sun printing method. He then continued his story and pointed out how he succeeded in the synthesis of resins, far superior in behavior and properties to the resins of nature, and called it Bakelite. This opened a new field of endless industrial applications, and, at the same time, stimulated vigorous further research in all industrial countries, thus bringing about the growth of the modern industry of synthetic plastics.

The subject was illustrated by many specimens of Bakelite products and a moving picture film was shown for the first time, entitled "The Story of Bakelite." Lowell Thomas was the narrator and there was an accompaniment of music.

The Chairman thanked the speaker and announced that there would be an intermission of ten minutes to enable the audience to examine the specimens.

The meeting was then reconvened by Mr. Philip C. Staples, President, and the voting members again took their seats for the purpose of discussing the proposed amendments to the By-Laws.

The ARTICLES were taken up Section by Section and resulted in the following action:

ARTICLE I. Action deferred until after consideration of other ARTICLES.

ARTICLE II. *Section 1.* Moved that the class of Life Members be inserted. Motion seconded and not passed. Adoption of Section 1. as proposed was passed. *

Section 2, 3, 4, 5, 6, 7, and 8. Adopted as proposed.

ARTICLE III. Adopted as proposed.

ARTICLE IV. *Section 1.* Adopted.

Section 2. Not adopted. Old Section 2 retained.

Section 3. Adopted.

Section 4. Not adopted. Old Section 4 retained.

Section 5. Adopted with insertion of "Officers and" preceding Managers in next to last line.

Section 6. Adopted with insertion of "such other" and deletion of "the" at end of third line.

Section 7. Adopted.

ARTICLE V. Adopted.

ARTICLE VI. Adopted.

ARTICLE VII. Adopted with correction of title of Superintendent of Schools and President of Park Commission.

ARTICLE VIII. *Section 1 to 8 inclusive.* Adopted with substitution of "organization" in place of "first stated" in line six of Section 4.

Section 9. Amended and passed to read as follows, according to motion made and seconded:

> The Committee on Science and the Arts shall investigate current discoveries, inventions and other achievements in the sciences and their application in the mechanical and industrial arts with a view of affording such recognitions as lie within the power of the Institute to bestow. The Committee shall exercise independent judgment therein. In all matters of a general or administrative nature the Committee shall collaborate with the Secretary.

Section 10 and 11. Adopted.

Section 12. Adopted with insertion of "have charge of the Library and" after shall in second line.

Section 13, 14, 15, 16 and 17. Adopted.

ARTICLE IX. *Section 1.* Adopted.

Section 2. Adopted with deletion of last sentence.

Section 3. Changed to Section 4. and adopted. New Section 3. adopted to read "Twenty-four members shall constitute a quorum at any stated or special meeting."

ARTICLE X. Adopted.

It appearing that no changes were proposed affecting the present ARTICLE I of the By-Laws, and there being no necessity for action by holders of Stock of the Institute, ARTICLE I was adopted as presently written.

The following Resolution was then adopted:

Resolved that the proposed By-Laws as amended by the action of the members at this meeting, a copy of which is attached hereto as Exhibit A, be and they are hereby adopted as the By-Laws of the Institute.

Adjourned.

HENRY BUTLER ALLEN,
Secretary.

EXHIBIT A.

By-Laws of The Franklin Institute as adopted at the Stated Meeting, held October 20, 1937.

ARTICLE I.

STOCK.

Section 1. The Real and Personal Estates of the Institute as held upon the First day of January, One Thousand Eight Hundred and Eighty-one, shall be valued at One Hundred Thousand Dollars, and shall be represented by Ten Thousand Shares of Stock of the par value of Ten Dollars each. Said shares shall be divided into two classes, *viz.:*

First Class. Shares not registered for use: on which no annual payment shall be charged or collected, and the holders thereof shall not have the privileges of members of the Institute, but may, if of legal age, vote at any annual election for officers and managers upon the payment of One Dollar upon each share of stock on which they may desire to vote; provided, however, such shares have been held by the same person at least three months before such election.

Shares of the First Class may be converted into shares of the Second Class at the pleasure of the owners, provided the transfer be approved by the Board of Managers; but, when once so converted, they shall always continue in the Second Class.

Second Class. Shares registered for use: on which Twelve Dollars per annum shall be due and payable from resident members in advance on the first day of October in each year, except as hereinafter provided.

Non-resident holders of Second Class stock shall pay an annual fee of Five Dollars.

Section 2. The holders of Second Class stock shall be entitled to the use of the library, lectures and reading-room; and, if of legal age, to all other privileges of membership in the Institute, so long as they make the annual payment in advance; and shall, on the payment of One Dollar therefore, be entitled to a Certificate of Membership.

Section 3. If the annual dues for successive years remain unpaid at the expiration of two and a half years on any share of stock of the Second Class, such shares shall then become forfeited to the Institute; but such forfeiture may be remitted by a unanimous vote of the Board of Managers.

Section 4. Stock of the Second Class may be held in trust for persons not of legal age, and shall be liable to the payment of only one-half the annual fees due upon stock of Second Class held by persons of legal age; provided, that when such minors arrive at legal age, new certificates, subject to the full annual contribution, shall issue on payment of the customary fee.

Section 5. Certificates for the First Class stock may be issued for any number of shares in a single certificate; but every certificate for the Second Class shall be for one share only.

Section 6. No share of stock in the Second Class shall be transferred until all arrearages and fines are paid, and all books and tickets returned, and the transfer approved by the Board of Managers.

Section 7. All certificates of stock shall be signed by the President and Secretary; shall be issued by the Controller, and shall be transferable only on the books of the Institute by the owner, or his legal representative, on the surrender of the old certificate, and of a fee of twenty-five cents for each certificate.

Section 8. All subscriptions to stock shall be approved by the Board of Managers before the certificate can be issued.

ARTICLE II.

MEMBERS.

Section 1. All persons interested in the purposes and activities of the Institute and willing to further them may become members when elected by the Board of Managers, or in a manner prescribed by the Board, except as qualified by Section 6 of this ARTICLE. Membership shall consist of the following classes:

1. Student members
2. Associate members
3. Active members
4. Sustaining members
5. Honorary members

The Board of Managers may establish other classes of members, provided that the privileges enjoyed and dues paid by such other classes are not inconsistent with the privileges and dues of the classes of members specifically provided for by these By-Laws.

Section 2. Student members shall be under twenty-five years of age and shall pay annual dues of $2.00. They shall be entitled to unlimited free admission to the Museum and the Planetarium. Student members who are fourteen or more years of age may, if endorsed by a teacher or an Active member, have the use of the library upon the payment of additional annual dues of $1.00 but shall have no voting privileges or rights to hold office.

Section 3. Associate members shall pay annual dues of $5.00. They shall be entitled to unlimited free admission to the Museum and to the Planetarium, but shall have no voting privileges or rights to hold office. Upon the payment of $5.00 additional annual dues they shall have Family privileges as defined in Section 7 of this ARTICLE.

Section. 4. Active members shall be not less than twenty years of age. They shall pay annual dues of $15.00. Active members residing permanently at a distance of twenty-five miles or more from Philadelphia shall pay annual dues of $5.00. Active members shall be entitled to use the library, to receive one copy of the Journal of The Franklin Institute, to vote and to hold office. They shall be entitled to all the privileges of Associate Members and upon the payment of $5.00 additional annual dues shall be entitled to Family privileges.

Section 5. Sustaining members shall be not less than twenty years of age. They shall pay annual dues of not less than $50.00. They shall be entitled to all of the privileges of Active members and shall have Family privileges as defined in Section 7 of this ARTICLE free of additional charge.

Section 6. Honorary members shall be entitled to all of the privileges of sustaining members, except the right to vote and to hold office. They shall be nominated by the Board of Managers and shall be elected by four-fifths of the votes of the members present at any stated meeting of the Institute at which their nomination may be acted upon.

Section 7. Family privileges consist of the right to receive a card for each individual in the family of the member and resident with the member entitling the holder to unlimited free admission to the Museum and the Planetarium.

Section 8. Members belonging to classes of membership existing prior to the amendment of this ARTICLE shall be reclassified in a manner consistent with their former dues and privileges.

ARTICLE III.

PAYMENT OF DUES.

Section 1. The annual fees for membership shall be due and payable on the first day of January, April, July or October each year, whichever is nearest to the date of election, or as determined by the Board of Managers.

Section 2. Any member whose dues are more than two months in arrears shall have all the privileges of membership suspended until such time as all arrears are paid. Should the dues not be paid when they become six months in arrears the said member shall forfeit his membership.

Section 3. The Board may remit temporarily in whole or in part the dues of any member either by action in a particular case or by establishing regulations governing certain cases.

Section 4. Every person admitted to membership in the Institute shall be considered as liable for the payment of dues until he shall have resigned, been dropped or have been relieved therefrom by the Board of Managers.

Section 5. Resignations of memberships shall be made to the Board of Managers in writing, but need not be accepted until all dues and arrears up to date of resignation shall have been paid.

Section 6. The privileges and title of Associate Member may be obtained for life by paying therefor in one year the sum of $100. From this payment may be deducted one-half of the Student or Associate Membership dues paid by the member during the preceding ten years, but in no case shall the deduction exceed $50.00.

Section 7. The privileges and title of Active Member shall be enjoyed for

life or may be obtained for life by a member who has heretofore or who shall hereafter pay therefor, in one year, the sum of $300, except that a person residing permanently at a distance of twenty-five miles or more from Philadelphia may become an Active Member for life by paying therefor in one year the sum of $100. From this payment may be deducted one-half of the dues paid by the member during the preceding ten years, but in no case shall the deduction exceed one-half of said payment. Associate Members for life may become Active Members for life by paying therefor in one year the sum of $200.

Section 8. Firms, corporations, associations or individuals may nominate and subscribe for the membership dues of groups of members of any class or classes, at the annual dues provided for, subject to the approval of the Board as to any particular nominee. If the dues of these nominees amount to $100 or more in the aggregate, the firm, corporation, association or individual shall be known as an Affiliate of the Institute.

ARTICLE IV.

ELECTION OF OFFICERS.

Section 1. The officers shall be a President, not more than five Vice-Presidents, a Secretary, an Assistant Secretary, a Treasurer, two Assistant Treasurers, a Controller, a Librarian, a Director of the Benjamin Franklin Memorial and The Franklin Institute Museum, a Manager of Operations of the Benjamin Franklin Memorial and the Franklin Institute Museum, a board of twenty-four (24) Managers and such other officers as the Board of Managers may elect or appoint.

Section 2. At the annual meeting of the Institute the President, the Vice-Presidents, and the Treasurer shall be elected to serve one year, and eight Managers shall be elected each year to serve for three years; provided, that the officers now elected, or who may hereafter be elected, shall continue to serve until their successors be elected.

Section 3. All elections of the Institute shall be by letter ballot and no vote may be cast by proxy.

Section 4. Nominations for President, Vice-Presidents, Treasurer and Managers shall be made in writing at the stated meeting in the month of December. Each nomination paper must be signed by at least two members, who shall certify that the candidate will serve if elected. After the nominations are closed, the President shall appoint three members, who are neither officers nor nominees, to act as tellers of election. The list of nominees shall be posted at the Institute and incorporated (with directions for voting) in a ballot to be sent to each member by the Secretary at least one week before the date of election. Each ballot shall be accompanied by a return envelope addressed "To the Tellers of Election," and provided with a space for the signature of the member voting.

Section 5. On the date of the annual meeting, and at an hour previously designated by their chairman, the tellers shall meet at the Institute, and shall count all legal votes that have been received by mail or placed in the ballot box before eight o'clock P.M.; and when the count is completed they shall report to the annual meeting of the Institute the total number of ballots cast, together with the number of votes received by each candidate. Thereupon the presiding officer shall announce the names of the candidates who received the plurality of votes, and shall declare them elected officers and Managers of the Institute for the ensuing terms.

Section 6. At the organization meeting of the Board of Managers, the Board of Managers shall elect such other officers provided for in Section 1 of ARTICLE IV; shall elect or appoint such other officers as it may determine upon, and shall determine and fix the compensation, if any, to be paid to the officers so elected or appointed by them. The officers who are in office immediately prior to the annual meeting shall continue in office until their successors are elected or appointed by the Board of Managers as herein provided.

Section 7. Vacancies occurring in any office may be filled by the Board of Managers by election or appointment of persons to serve until the next annual election.

ARTICLE V.

BOARD OF MANAGERS.

Section 1. The Board of Managers shall have general charge and control of the Institute and of The Benjamin Franklin Memorial and The Franklin Institute Museum, and shall consist of twenty-four members elected as provided in ARTICLE IV. The President, the Vice-Presidents, the Secretary, the Treasurer, the Chairman of the Committee on Science and the Arts, and the Chairman of the Library Committee shall be ex officio members. A quorum of the Board of Managers shall be nine of the elected and ex-officio members. The Board of Managers may adopt such by-laws, rules and regulations for the governance of their affairs as are not inconsistent with the Charter and these By-laws.

Section 2. They shall present, through the President, at the annual meeting of the Institute, a report of the condition of the affairs of the Institute.

Section 3. They shall hold stated meetings in each month except in July and August.

Section 4. Special meetings may be called by the President at his discretion and shall be called by him on written request of the Executive Committee or of any seven members of the Board. In case of his absence or refusal to act, such special meeting shall be called by the Secretary.

Section 5. Members who have not attended five regular meetings in the twelve months prior to the stated meeting of the Institute in December, shall be reported thereat as having resigned, unless it be unanimously voted by the Board at that meeting, that such member has been absent for sufficient reason.

Section 6. All vacancies on the Board of Managers shall be filled by the Board until the next annual meeting of the Institute.

Section 7. The Board of Managers may elect an Executive Committee consisting of five of its Members with such authority to act on behalf of the Board as the Board may delegate.

ARTICLE VI.

DUTIES OF OFFICERS.

Section. 1. The President shall be the executive head of the Institute and, under the supervision of the Board of Managers, shall have general charge of the affairs of the Institute. He shall preside at all meetings of the Institute and of the Board of Managers and shall be ex officio a member of all Committees.

Section 2. The Vice-Presidents shall exercise the duties of the President in his absence in the order of their seniority in office.

Section 3. The Secretary shall have general administrative supervision over all of the affairs of the Institute other than those matters specifically delegated by these By-Laws to the Executive Committee, Finance Committee, and Treasurer. He shall keep the minutes of all meetings of the Institute and of the Board of Managers, and shall perform all the duties usually pertaining to the office of Secretary. He shall prepare the annual budget, submit it to the Finance Committee for first approval, and to the Board of Managers for final approval. He shall be an ex officio member of all Committees. He shall report to the President. In the absence or disability of the Secretary, the Assistant Secretary shall perform his duties.

Section 4. The Director of The Benjamin Franklin Memorial and The Franklin Institute Museum shall have general administrative supervision over the Memorial and Museum, of the exhibits therein displayed, and of the activities centering in the Museum. He shall annually appoint the members of the scientific staff of the Museum, subject to the approval of the Secretary and of the Board of Managers. He may be appointed by the Board of Managers an ex officio member of any Committee. He shall report to the Secretary.

Section 5. The Treasurer shall have custody of all moneys received from the Committee on Finance, together with all moneys received by the Institute from dues, admissions and other incidental collections. He shall deposit in the name of the Institute, in such bank or banks as the Board of Managers may direct, all moneys in his custody. He shall disburse such moneys only upon vouchers certified by the Controller or, in the absence or disability of the Controller, by the Auditor or the Secretary. He shall keep accurate accounts of the

income and disbursements of the Institute, shall report current receipts and payments at each stated meeting of the Board of Managers, and shall make a detailed statement of the financial condition of the Institute at its annual meeting. He shall give bond to an amount, and with such surety, as the Board of Managers shall determine. He shall report to the President. In the absence or disability of the Treasurer, the Assistant Treasurers shall, in the order of their seniority in office, perform his duties.

Section 6. The Controller shall keep the detailed accounts of the Institute, shall collect all moneys due the Institute and shall deposit them in the Treasurer's account. He shall approve all expenditures for payment. He shall act as the business agent of all publications of the Institute, except as the Board of Managers may specifically otherwise from time to time provide. He shall perform such other duties as are assigned to him by the Secretary. He shall report to the Secretary.

Section 7. The Librarian shall have immediate charge of the library and reading-room of the Institute. He shall report to the Secretary.

Section 8. The manager of Operations of The Benjamin Franklin Memorial and The Franklin Institute Museum shall have immediate charge of The Benjamin Franklin Memorial and The Franklin Institute Museum. He shall have charge of the maintenance and care of all real estate properties of the Institute, and of its shops. He shall report to the Director of The Benjamin Franklin Memorial and The Franklin Institute Museum.

ARTICLE VII.

BOARD OF COUNCILLORS.

The Board of Councillors shall consist of not more than fifty members and shall embrace, as ex officio members, the Governor of Pennsylvania, the Chief Justice of the Supreme Court of Pennsylvania, the Mayor of the City of Philadelphia, the President of the City Council of Philadelphia, the President of the Board of Public Education and the Superintendent of Schools of the City of Philadelphia, the Provost and the President of the University of Pennsylvania, the President of Commissioners of Fairmount Park, the President of the American Philosophical Society, the President of the Poor Richard Club, and the President and Secretary of The Franklin Institute, which two latter shall respectively be Chairman and Secretary of the Board of Councillors. Additional members shall be nominated by the President or Secretary of the Institute and elected by the Board of Managers, at such intervals as the Board of Managers may see fit. The Board of Councillors shall meet at the call of its Chairman or of the Board of Managers for the consideration of any matter that pertains to the welfare of the Institute. The Secretary shall from time to time send to the members of the Board of Councillors a report of the activities and accomplishments of the Institute.

ARTICLE VIII.

COMMITTEES OF THE INSTITUTE.

Section 1. There shall be the following Standing Committees of the Institute:

1. Bartol Research Foundation Committee.
2. Biochemical Research Foundation Committee.
3. Committee on Science and the Arts.
4. Endowment Committee.
5. Finance Committee.
6. Library Committee.
7. Meetings Committee.
8. Membership Committee.
9. Memorial and Museum Committee.
10. Publications Committee.

Section 2. Each standing committee of the Institute shall consist of at least ten members, not more than five of whom shall be members of the Board of Managers, except that the Committee on Science and the Arts shall consist of sixty-six members, without limitation as to the number who may be members of the Board of Managers, and except that the Bartol Research Foundation Committee shall consist of twelve members as provided for in Section 7 of this ARTICLE.

Section. 3. The members of each committee shall serve one year, except that members of the Committee on Science and the Arts shall serve three years.

Section 4. The members of each committee, other than ex officio members specifically provided for by these By-Laws, shall be appointed by the President and approved by the Board of Managers at the organization meeting of the Board following the annual meeting, except that each year but twenty-two members of the Committee on Science and the Arts shall be so appointed and approved.

Section 5. The Chairman of each committee shall be designated by the President, except that the Library Committee and the Committee on Science and the Arts shall select their chairmen. A chairman who is not an elected or ex officio member of the Board of Managers shall have the privilege of the floor at meetings of the Board but shall not have the right to vote.

Section 6. Each committee shall report monthly through its Chairman or through the Secretary, as it may elect, to the Board of Managers.

Section 7. The Bartol Research Foundation Committee shall consist of twelve members, including the President and the Secretary of the Institute and the Director of the Bartol Research Foundation as ex officio members and nine members of the Institute of whom not more than four shall be members of the Board of Managers. The Committee shall, after consultation with the Director of the Bartol Research Foundation and subject to the approval of the Board of Managers, collaborate with the Secretary in carrying out the purposes and determining the policies of the Bartol Research Foundation. It shall appoint the Director and the Staff of the Laboratories, subject to the approval of the Board of Managers. The Director of the Bartol Research Foundation, to whom all other employees of the Foundation shall report, shall have charge of the scientific activities of the Foundation and shall report on all matters to the Committee or to the Secretary, as the Committee may elect.

Section 8. The Biochemical Research Foundation Committee shall report to the Board of Managers from time to time on the condition of the affairs and operation of said Foundation and shall be available to the Director of the Biochemical Research Foundation and its Advisory Council for collaboration and advice.

Section 9. The Committee on Science and the Arts shall investigate current discoveries, inventions and other achievements in the sciences and their application in the mechanical and industrial arts with a view of affording such recognitions as lie within the power of the Institute to bestow. The Committee shall exercise independent judgment therein. In all matters of a general or administrative nature the Committee shall collaborate with the Secretary.

Section 10. The Endowment Committee shall, in collaboration with the Secretary, encourage the gift of funds to the Institute.

Section 11. The Finance Committee shall have charge and supervision of all securities and general funds of the Institute including any funds derived from bequests and endowments. It shall invest all general funds available for investment. It shall pay the income from all investments to the Treasurer of the Institute. It shall approve the annual budget as prepared by the Secretary, before it is submitted to the Board of Managers for final approval, and shall thereafter make such examinations of financial results of operations as will insure compliance with the annual budget. It may, with the approval of the Board of Managers, appoint a Trust Company of the City of Philadelphia to act as Fiscal Agent under the direction of the Committee.

Section 12. The Library Committee shall have charge of the library and, in collaboration with the Secretary, purchase books and publications suitable to and consonant with the purposes of the library of the Institute.

Section 13. The Meetings Committee shall, in collaboration with the Secretary, secure for presentation before the Institute papers dealing authoritatively with subjects of import in the fields of science, engineering and industry.

Section 14. The Membership Committee shall, in collaboration with the Secretary, promote the several memberships defined in ARTICLE II of these By-Laws.

Section 15. The Memorial and Museum Committee shall, in collabora-

tion with the Secretary, be of counsel and advice to the Director of The Benjamin Franklin Memorial and The Franklin Institute Museum, and with the scientific staff of the Museum concerning the activities and the exhibits of both the Memorial and the Museum.

Section 16. The Publications Committee, in collaboration with the Secretary, shall have charge of all publications of the Institute other than publications of the Bartol Research Foundation.

Section 17. Each committee shall organize and adopt rules as it sees fit, subject to the provisions of these By-Laws and the approval of the Board of Managers.

ARTICLE IX.

MEETINGS.

Section 1. The Institute shall hold stated meetings on the third Wednesday of each month except in June, July, August and September, at 8:30 P.M.

Section 2. Special meetings shall be called by the President upon the order of the Board of Managers or within ten days upon the written application of twenty-four voting members of the Institute.

Section 3. Twenty-four members shall constitute a quorum at any stated or special meeting.

Section 4. The Annual Meeting of the Institute shall be held on the third Wednesday of January of each year at 8:30 P.M. Elections at Annual Meetings shall not result from the poll of less than forty-eight ballots cast in accordance with ARTICLE IV, Section 5 of these By-Laws.

ARTICLE X.

AMENDMENTS.

These By-Laws may be altered or amended at any stated meeting of the members of the Institute, provided notice in writing, signed by two members, of the proposed alteration or amendment, shall be given to the Board of Managers two months prior to the said meeting, except that amendments to ARTICLE I, relating to capital stock, must be ratified subsequently by a majority of the stock represented at a meeting specially called for this purpose.

LIBRARY NOTES.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 601 readers made use of the facilities during the twenty-five days of August.

RECENT ADDITIONS

Architecture and Building.

TOROK, ELMER. Air Conditioning in the Home. First Edition. 1937.

Astronomy.

BOK, BART J. The Distribution of the Stars in Space. 1937. Astrophysical Monographs Sponsored by The Astrophysical Journal.

VAN DEN BERGH, G. Astronomy for the Millions. Translated from the Dutch by Joan C. H. Marshall and Th. de Vrijer. 1937.

Aviation.

PIERCY, N. A. V. Aerodynamics. 1937.

TITTERTON, GEORGE F. Aircraft Materials and Processes. 1937.

Biochemistry.

CUMBERBATCH, ELKIN P. Diathermy Including Diathermotherapy and Other Forms of Medical and Surgical Electrothermic Treatment. Third Edition. 1937.

TANNER, FRED WILBUR. Bacteriology. A Text-book of Microörganisms. Third Edition. 1937.

WENT, F. W., AND KENNETH V. THIMANN. Phytohormones. 1937. Experimental Biology Monographs.

Biography.

GOODMAN, NATHAN G. Benjamin Franklin's Own Story. His Autobiography Continued from 1759 to his Death in 1790 with a Biographical Sketch Drawn from his Writings. 1937.

Chemistry and Chemical Technology.

BAILEY, KENNETH C. The Retardation of Chemical Reactions. 1937.

BUZÁGH, A. VON. Colloid Systems. A Survey of the Phenomena of Modern Colloid Physics and Chemistry. Translated by Otto B. Darbishire. Edited by William Clayton. 1937.

FEIGL, FRITZ. Qualitative Analysis by Spot Tests Inorganic and Organic Applications. Translated from the Latest German Edition by Janet W. Matthews. 1937.

GLASSTONE, S. The Electrochemistry of Solutions. Second Edition, Revised and Enlarged. 1937.

Institution of Chemical Engineers. Transactions. Volume 14. 1936.

Institution of Petroleum Technologists. Petroleum: Twenty-five Years Retrospect 1910–1935. No date.

Institution of Petroleum Technologists. Standard Methods for Testing Petroleum and Its Products. Third Edition. 1935.

Kaiser-Wilhelm-Institut für Kohlenforschung in Mülheim-Ruhr. Arbeiten. Gesammelte Abhandlungen zur Kenntnis der Kohle. Herausgegeben von Professor Dr. Franz Fischer. Zwölfter Band. 1937.

KOLTHOFF, I. M. Acid-Base Indicators. Translated by Charles Rosenblum. 1937.

LANGE, NORBERT ADOLPH. Handbook of Chemistry. Second Edition. Revised and Enlarged. 1937.

MIALL, STEPHEN, AND LAURENCE MACKENZIE MIALL. Chemistry. Matter and Life. 1937.

MITCHELL, C. AINSWORTH. Documents and their Scientific Examination. 1935.

MOYER, JAMES A. Oil Fuels and Burners with Special Reference to Automatic Domestic Types. First Edition. 1937.

NAUNTON, W. J. S. Synthetic Rubber. 1937.

PREGL, FRITZ. Quantitative Organic Microanalysis of Fritz Pregl by Dr. Hubert Roth. Third English Edition Translated from the Fourth Revised and Enlarged German Edition by E. Beryl Daw. 1937.

SCHLESINGER, H. J. General Chemistry. Third Edition. 1937.

THORPE, JOCELYN FIELD, AND M. A. WHITELEY. Thorpe's Dictionary of Applied Chemistry. Fourth Edition. Volume 1. 1937.

ZAMBONI, G. A. Motor Oils and their Application. 1936.

Electricity and Electrical Engineering.

GLASGOW, R. S. Principles of Radio Engineering First Edition. 1936. Electrical Engineering Texts.

KLINEFELTER, LEE M. Electrical Occupations. Covering the Entire Field of Electrical Occupations Available to Boys when they Grow up. 1937.
LANGSDORF, ALEXANDER S. Theory of Alternating Current Machinery. First Edition. 1937. Electrical Engineering Texts.
PARR, G. The Low Voltage Cathode Ray Tube and its Applications. 1937.
TERMAN, FREDERICK EMMONS. Radio Engineering. Second Edition. 1937.

Geology.

EMMONS, WILLIAM HARVEY. Gold Deposits of the World with a Section on Prospecting. First Edition. 1937.
FOX, CYRIL S. A Comprehensive Treatise on Engineering Geology. 1935.
U. S. Foreign Minerals Division. Bureau of Mines. Mineral Raw Materials. Survey of Commerce and Sources in Major Industrial Countries. 1937.

Manufactures.

Heating and Piping Contractors National Association. Standard Manual on Pipe Welding. 1931.
U. S. Department of Commerce. Stories of American Industry. 1937.

Mathematics.

VAN VOORHIS, MERRILL G. How to Make Alignment Charts. 1937.

Metallurgy.

KINZEL, A. B., AND WALTER CRAFTS. The Alloys of Iron and Chromium. Volume 1: Low-Chromium Alloys. First Edition. 1937. Alloys of Iron Research Monograph Series.

Meteorology.

TREWARTHA, GLENN T. An Introduction to Weather and Climate. First Edition. 1937.

Military Engineering.

LIEPMANN, HEINZ. Poison in the Air. Translated from the German by Eden and Cedar Paul. 1937.

Photography.

DAVY, CHARLES, Editor. Footnotes to the Film. 1937.
Modern Photography 1937–38.

Physics.

American Institute of Physics. Physics in Industry. 1937.
EPSTEIN, PAUL S. Textbook of Thermodynamics. 1937.
FERMI, ENRICO. Thermodynamics. 1937.
LUCKIESH, MATTHEW, AND FRANK K. MOSS. The Science of Seeing. 1937.
MILLER, DAYTON CLARENCE. Sound Waves: their Shape and Speed. A Description of the Phonodeik and its Applications and a Report on a Series of Investigations Made at Sandy Hook Proving Ground. 1937.
Physical Society. Reports on Progress in Physics. Volume 3. 1937.
TIMOSHENKO, S., AND D. H. YOUNG. Engineering Mechanics. First Edition. Two volumes. 1937.

University of Pittsburgh. Members of the Physics Staff. Cutline of Atomic Physics. Second Edition. 1937.

WILLIAMS, SAMUEL ROBINSON. Foundations of College Physics. 1937.

Scientific Essays.

DANTZIG, TOBIAS. Aspects of Science. 1937.

GAUSS, CARL FRIEDRICH. Inaugural Lecture on Astronomy and Papers on the Foundations of Mathematics. Translated and Edited by G. Waldo Dunnington. 1937.

GRAY, GEORGE W. The Advancing Front of Science. 1937.

Statistics.

U. S. Bureau of Foreign and Domestic Commerce. Selected Trade Associations of the United States. 1937 Edition. National and Interstate. 1937.

U. S. Bureau of Foreign and Domestic Commerce. Sources of Current Trade Statistics by Jettie Turner. 1937. Market Research Series no. 13.

Sugar.

Annuaire Sucrier. Soixante-deuxième Année. 1936.

CAMPBELL, CLYDE H. Campbell's Book of Canning, Preserving and Pickling. Revised Edition. 1937.

JONES, OSMAN, AND T. W. JONES. Canning Practice and Control. 1937.

PRESCOTT, SAMUEL C., AND BERNARD E. PROCTOR. Food Technology. First Edition. 1937.

BOOK REVIEWS.

ASTRONOMY FOR THE MILLIONS, by Prof. G. Van Den Bergh. Translated from the Dutch by Joan C. H. Marshall and Th. de Vrijer. 370 pages, illustrations, 15 × 21 cms. New York, E. P. Dutton and Company, Inc., 1937. Price $3.50.

As the title indicates, this book is intended for popular consumption, therefore we may expect the language to be such that everyone can easily understand. Also we can expect a revelation of informative matter concerning the subject. Just how well this is done can easily be determined by merely examining and reading portions of the book.

The author uses a rather unusual method here which not only impresses the reader with what should be stressed but it furnishes entertainment in so doing. It is presented from the angle of giving proof of certain postulates. As an illustration, the author discusses the roundness of the earth and then follows with direct proofs of its roundness, proofs that are apparent to everyone. In the same way the earth's rotation on its axis is discussed as is also the revolution around the sun. To be sure, the entire book is not written this way, for when the occasion arises, a more direct informative approach is used as in describing relative dimensions and distances. The entire subject matter of the book is well linked together with both methods and with a humorous touch here and there.

There are twelve chapters beginning with the earth and proceeding through others on the moon, the sun, the planets, the stars etc. At the very beginning of

each, of course, the treatment is exceedingly elementary. This is true to the extent that should the reader be somewhat impulsive or impatient, the book may be tossed aside as too elementary or possibly too lengthy. This may have been overcome in the construction of the book either by shortening certain elementary parts of some sections or eliminating some of the proofs of popular assumptions. The great majority of readers however, will not be so bothered for one has only to read a few pages to become acquainted with the author's way and the parts that seem elementary can be skipped and the thread easily picked up later on.

Throughout the book there are simple diagrams and illustrations to bring out certain points. The chapters follow each other in a progression that is well thought out. It leads up to a conception of the universe and a discussion of the past and future, and leaves the reader with the question "Are there other inhabited worlds"?

The book can be read as easily as a favorite novel. It provides informative entertainment.

R. H. OPPERMANN.

FOUNDATIONS OF COLLEGE PHYSICS, by Samuel Robinson Williams. 630 pages, plates, illustrations, tables, 15 × 23 cms. Boston, Ginn and Company, 1937. Price $4.00.

Much emphasis is being placed, these days, on the method of approach in the teaching of scientific subjects. It is averred that criticisms aimed at the study of physics, for instance, as being uninteresting, dry, and difficult are due to the incorrect method of approach, used in textbooks and in laying the foundations. As a result of this and other charges authors in recent years have endeavored to use various ways of making their subjects interesting and at the same time gain the results of imparting sufficient knowledge for practical use and for further study.

The author of this book states that that is one of the objects here. The other is to inculate a valuable method of studying. Both are to achieve the same ends. He has divided his book into six parts beginning with an introductory answer to the query, "What is Physics," followed by a brief discussion on the principles of metrology. Much stress is laid on a thorough understanding of systems of units used in physics and this is quite well covered. The text, however, almost exclusively uses the centimeter-gram-second system. The parts of the general subject then presented are in order, mechanics, sound, heat, electricity and magnetism, and optics.

At the end of each chapter can be found a suggestive outline for guidance in summarizing its contents. The student is urged to write a summary after studying each chapter and with this before him, he should test his ability to expand the statements given in the summary into a well rounded and comprehensive discussion. Also at the end of each chapter is a list of problems in which applications of principles are involved. A subject index completes the book.

It seems the author has spent no little effort in making this book a most convenient and interesting tool in the acquirement of a knowledge of fundamental physics. Where mathematical formulæ are used he adds color in giving interpretation of the significance in applying them to objects and operations of common observance. Illustrations shown to bring out explanations, are of like simple

variety. Because of methods such as these and the careful compilation of the material it will pay anyone contemplating the study of physics to examine this book. The mathematical prerequisites include some knowledge of trigonometry.

R. H. OPPERMANN.

THE SCIENCE OF SEEING, by Matthew Luckiesh and Frank K. Moss. 548 pages, illustrations, tables, 14 × 22 cms. New York, D. Van Nostrand Company, Inc., 1937. Price $6.00.

In their new book the authors have presented new concepts and criteria, new devices and methods and new data which have contributed a new understanding of the factors which influence seeing.

The conditions for easiest and most certain seeing are disclosed and the great range of problems involving the visual sense contribute new data of far-reaching importance.

The subject of conservation of vision—safety, light and lighting,—comparative merits of different light sources, glare and its elimination, etc.—are fully and simply explained.

All the fundamental knowledge, basic principles and pertinent data obtained by actual measurement, pertaining to vision, seeing and lighting, have been organized into a single presentation. Conditions for easiest and most certain seeing are fully investigated. Criteria are established for the wide variation in the conditions of seeing occurring even in the same task—thus conditions of illumination easiest for reading are shown to vary with the size, style and spacing of type, the length of lines, the character of paper and ink, the difficulty of the context, the frame of mind of the subject, etc. Definite relationships are established between brightness, contrast, size and visual angle.

This book puts at your command a vast amount of data obtained by the new instruments which have been developed to provide a real quantitative knowledge of visual problems. They include visibility meters, pupillometers, ophthalmic sensitometers, brightness meters, reflectance gauges, visual acuity apparatus and many other highly specialized forms of equipment.

Hundreds of pertinent topics, such as night-blindness, color-blindness, visual factors of safety and influence of background upon visibility, contribute to the immense reference value of this comprehensive book.

JAMES D. LEE, JR.

PRINCIPLES OF QUANTUM MECHANICS, by Alfred Landé. 115 pages, illustrations, 14 × 22 cms. New York, The Macmillan Company, 1937. Price $2.25.

The aim of this book, according to the author, is to develop the principles of quantum mechanics on the basis of a few standard observations and to eliminate certain contradictory ideas that have no counterpart in empirical facts. In doing this he emphasizes the perfect complementarity of the wave and the corpuscular picture and contrasts every statement made in wave language to a complementary statement expressed in corpuscular terms.

The book begins with a chapter on elementary theory of observation which gives the principle of complementarity, then proceeds through the principle of

uncertainty, interference, correspondence, and invariance. There are some 115 pages of technical discussions fully indexed as to literature, names, and subjects.

The book should appeal to those already familiar with the quantum theory but who wish to clarify it along certain lines.

R. H. OPPERMANN.

ATOMIC ARTILLERY, MODERN ALCHEMY FOR EVERYMAN, by John Kellock Robertson. 117 pages, plates, illustrations, 13 × 20 cms. New York, D. Van Nostrand Company, Inc., 1937. Price $2.25.

The frontiers of man's knowledge of our physical surroundings are receiving increasing attention because during recent years there have been made remarkable discoveries. These are of such magnitude and frequency that it is not uncommon to find notices of them in the news. As a result there has arisen a demand for a simplification of what is going on and many minds have taken up the task of explanation in popular language. This book is an attempt in that direction and is limited, of course, to atomic physics.

The task is not an easy one and probably the most difficult part of it is to lay the foundation i.e. to give the layman sufficient knowledge of general physics so that he can appreciate the advanced work. In order to do this, the author must have made a careful analysis before actually entering his work. First he covers very generally explanations of elements and compounds, atoms and molecules; then atomic weights and numbers. Next he leads the reader to the subject of static electricity which is brief.

Upon this foundation is built the structure of the book. The description of particles used as projectiles, is started with a discussion on cathode rays, how they are created and of what they are composed. Then there is a summary of the use of electrons as projectiles and, reverting back to foundation material, a further examination of the atom is made. A great many more projectiles are then discussed both those obtained by man and those provided by nature.

The subject of transmutation is probably the most interesting in the whole book. It is treated from the standpoint of the projectiles used, the apparatus and method, and the effects and results produced. The electrostatic generator and the cyclotron are described. The use of protons, neutrons, deutrons as bullets for nuclear bombardment as well as the use of photons are all covered. Near the end of the book, the author answers the question that naturally arises in the mind of the reader as to why spend time, energy, and money to investigate the smashing of the atom, especially when there is no practical reward in sight. Illustrations are given to answer this question and there is opened to the reader some of the possibilities which might ensue.

The book is entirely descriptive and practically no mathematics are used. There is a subject index which should prove very helpful as reference particularly when one wishes to refresh the memory on simple definitions of the more common terms used. Any person of average schooling who desires to become acquainted with this subject to the extent for light conversation would do well to read this book.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 586, Airfoil Section Characteristics as Affected by Variations of the Reynolds Number, by Eastman N. Jacobs and Albert Sherman. 41 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1937. Price 15 cents.

An investigation of a systematically chosen representative group of related airfoils was made in the N. A. C. A. variable-density wind tunnel over a wide range of the Reynolds Number extending well into the flight range. The tests were made to provide information from which the variations of airfoil section characteristics with changes in the Reynolds Number could be inferred and methods of allowing for these variations in practice could be determined. This work is one phase of an extensive and general airfoil investigation being conducted in the variable-density tunnel and extends the previously published researches concerning airfoil characteristics as affected by variations in airfoil profile determined at a single value of the Reynolds Number.

The object of this report is to provide means for making available as section characteristics at any free-air value of the Reynolds Number the variable-density tunnel airfoil data previously published. Accordingly, the various corrections involved in deriving more accurate airfoil section characteristics than those heretofore employed are first considered at length and the corrections for turbulence are explained. An appendix is included that covers the results of an investigation of certain consistent errors present in test results from the variable-density tunnel. The origin and nature of scale effects are discussed and the airfoil scale-effect data are analyzed. Finally, methods are given of allowing for scale effects on airfoil section characteristics in practice within ordinary limits of accuracy for the application of variable-density-tunnel airfoil data to flight problems.

Report No. 592, Full-Scale Tests of N. A. C. A. Cowlings, by Theodore Theodorsen, M. J. Brevoort and George W. Stickle. 30 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1937. Price 15 cents.

A comprehensive investigation has been carried on with full-scale models in the N. A. C. A. 20-foot wind tunnel, the general purpose of which is to furnish information in regard to the physical functioning of the composite propeller-nacelle unit under all conditions of take-off, taxying, and normal flight. This report deals exclusively with the cowling characteristics under conditions of normal flight and includes the results of tests of numerous combinations of more than a dozen nose cowlings, about a dozen skirts, two propellers, two sizes of nacelle, as well as various types of spinners and other devices.

The optimum shape of a low-drag cowling has been determined. The shape of the leading edge and the contours of the exit passage are the cause of large losses when improperly designed. The importance of providing means for regulating the quantity of cooling air to the minimum that will prevent excessive losses at high speeds has been demonstrated. The N. A. C. A. cowlings show a remarkably high efficiency when considered as a pump for the cooling air. The superiority of a baffled over an unbaffled engine has been verified and it has,

furthermore, been shown that tightly fitting baffles are superior to the deflector type.

Report No. 594, Characteristics of Six Propellers Including the High-Speed Range, by Theodore Theodorsen, George W. Stickle and M. J. Brevoort. 38 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1937. Price 15 cents.

This investigation is part of an extensive experimental study that has been carried out at full scale in the N. A. C. A. 20-foot tunnel, the purpose of which has been to furnish information in regard to the functioning of the propeller-cowling-nacelle unit under all conditions of take-off, climbing, and normal flight. This report presents the results of tests of six propellers in the normal and high-speed flight range and also includes a study of the take-off characteristics. The range of the advance-diameter ratio has been extended far beyond that of earlier full-scale experiments at the Laboratory, blade-angle settings up to 45° being included, which are equivalent to air speeds of more than 300 miles per hour for propellers of normal size and revolution speed. All the propellers were tested in conjunction with a standard nacelle unit equipped with half a dozen representative N. A. C. A. cowlings.

The results show very striking differences in the aerodynamic qualities of the various propellers, particularly in the high-speed range. Also of interest is the fact that the conventional propeller is shown to reach its peak efficiency in a range of 200 to 350 miles per hour and at a blade angle of approximately 35°. The inadequacy of using the propulsive efficiency unconditionally as a figure of merit is shown. This efficiency, defined in conventional manner, is found actually to exceed unity in certain cases, owing to the fact that certain cowlings show a decreased drag in the propeller slipstream. The adoption of some standard nacelle unit is therefore recommended as a basis for the comparative testing of propellers. The experimental results are presented in convenient charts. Charts for practical use in selecting propeller diameters and charts for choosing the optimum blade-angle setting in the take-off range are given in an appendix.

Report No. 597, Air Propellers in Yaw, by E. P. Lesley, George F. Worley and Stanley Moy. 15 pages, illustrations, tables, 23 × 29 cms. Washington, Government Printing Office, 1937. Price 10 cents.

Tests of a 3-foot model propeller at four pitch settings and at 0°, 10°, 20°, and 30° yaw were made at Stanford University. In addition to the usual propeller coefficients, cross-wind and vertical forces; and yawing, pitching, and rolling moments were determined about axes having their origin at the intersection of the blade axis and the axis of rotation.

The tests showed that the maximum efficiency was reduced only slightly for angles of yaw up to 10° but that at 30° yaw the loss in efficiency was about 10 per cent. In all cases the cross-wind force was found to be greater than the cross-wind component of the axial thrust. With a yawed propeller an appreciable thrust was found for V/nD for zero thrust at zero yaw. Yawing a propeller was found to induce a pitching moment that increased in magnitude with yaw.

Report No. 600, An Analysis of the Factors that Determine the Periodic Twist of an Autogiro Rotor Blade, with a Comparison of Predicted and Measured Results, by John B. Wheatley. 11 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1937. Price 10 cents.

An analysis is presented of the factors that determine the periodic twist of a rotor blade under the action of the air forces on it. The results of the analysis show that the Fourier coefficients of the twist are linear expressions involving only the tip-speed ratio, the pitch setting, the inflow coefficient, the pitching-moment coefficient of the blade airfoil section, and the physical characteristics of the rotor blade and machine. The validity of the analysis was examined by using it to predict the twist of a rotor whose twist characteristics had previously been measured in flight. The agreement between the calculated and experimental results was satisfactory. An examination of the assumption used in the analysis—that the twist is a linear function of the radius—disclosed that the approximation introduced no appreciable error. From this examination, a formula for the torsional rigidity of the rotor blade was derived.

Report No. 603, Wind-Tunnel Investigation of Wings with Ordinary Ailerons and Full-Span External-Airfoil Flaps, by Robert C. Platt and Joseph A. Shortal. 22 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1937. Price 10 cents.

An investigation was carried out in the N. A. C. A. 7- by 10-foot wind tunnel of an N. A. C. A. 23012 airfoil equipped, first, with a full-span N. A. C. A. 23012 external-airfoil flap having a chord 0.20 of the main airfoil chord and with a full-span aileron with a chord 0.12 of the main airfoil chord on the trailing edge of the main airfoil and equipped, second, with a 0.30-chord full-span N. A. C. A. 23012 external-airfoil flap and a 0.13-chord full-span aileron. The results are arranged in three groups, the first two of which deal with the airfoil characteristics of the two airfoil-flap combinations and with the lateral-control characteristics of the airfoil-flap-aileron combinations. The third group of tests deals with several means for balancing ailerons mounted on a special large-chord N. A. C. A. 23012 airfoil model with and without a 0.20-chord N. A. C. A. 23012 external-airfoil flap. The tests included an ordinary aileron, a curtained-nose balance, a Frise balance, and a tab.

The results obtained for the $0.30c_w$ flap verify the conclusion made from previous tests of the $0.20c_w$ flap combination, namely, that external-airfoil flaps applied to the N. A. C. A. 230 airfoil sections give characteristics more favorable to speed range, to low power requirements in flight at high lift coefficients, and to low flap-operating moments than do other types of flap in general use. The ailerons can produce large rolling moments with relatively small adverse yawing moments in flight conditions ranging from high speed to minimum speed. The nose balance and Frise balance were ineffective in reducing the stick forces required for a given control effectiveness, but the use of tabs in combination with a differential aileron motion provided a means of obtaining desirable stick forces throughout the flight range. The aerodynamic advantages of this aileron-flap combination appear to outweigh probable design difficulties.

Report No. 609, Experimental Investigation of Wind-Tunnel Interference on the Downwash Behind an Airfoil, by Abe Silverstein and S. Katzoff. 8 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1937. Price 10 cents.

The interference of the wind-tunnel boundaries on the downwash behind an airfoil has been experimentally investigated and the results have been compared with the available theoretical results for open-throat wind tunnels. As in previous studies, the simplified theoretical treatment that assumes the test section to be an infinite free jet has been shown to be satisfactory at the lifting line. The experimental results, however, show that this assumption may lead to erroneous conclusions regarding the corrections to be applied to the downwash in the region behind the airfoil where the tail surfaces are normally located. The results of a theory based on the more accurate concept of the open-jet wind tunnel as a finite length of free jet provided with a closed exit passage are in good qualitative agreement with the experimental results.

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Industrial Chemistry, an elementary treatise for the student and general reader, by Emil Raymond Riegel. Third edition, 851 pages, plates, illustrations, tables, 15 × 23 cms. New York, Reinhold Publishing Corporation, 1937. Price $5.75.

Principles of Quantum Mechanics, by Alfred Landé. 115 pages, illustrations, 14 × 22 cms. New York, The Macmillan Company, 1937. Price $2.25.

Atomic Artillery, modern alchemy for everyman, by John Kellock Robertson. 177 pages, plates, illustrations, 13 × 20 cms. New York, D. Van Nostrand Company, Inc., 1937. Price $2.25.

Introduction to Physiological Optics, by James P. C. Southall. 426 pages, plates, illustrations, 16 × 25 cms. New York, Oxford University Press, 1937. Price $5.50.

Polymerization and Its Applications in the Fields of Rubber, Synthetic Resins, and Petroleum, by Robert E. Burk, Howard E. Thompson, Archie J. Weith and Ira Williams. 312 pages, illustrations, tables, 16 × 23 cms. New York, Reinhold Publishing Corporation, 1937. Price $7.50.

Experimental Radio, by R. R. Ramsey. Fourth edition, 196 pages, illustrations, 15 × 23 cms. Bloomington, Indiana, Ramsey Publishing Company, 1937. Price $2.75.

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